UNITED STATES DEPARTMENT OF AGRICULTURE
FOREIGN AGRICULTURAL SERVICE

RESULTS OF THE VEGETATIVE INDEX CORRELATION STUDY

FIRST ISSUE

APPROVED BY:

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1 REASON FOR ISSUANCE

To present the results of the Vegetative Index Correlation Study to the Crop Condition Assessment Division. The results of the study will be used in a follow-on study designed to determine the relationship(s) of the vegetative indices to crop conditon parameters such as plant height, plant density and yield.

2 COVERAGE

The results of the study are to be used by the Crop Condition Assessment Division staff in future analysis of the relationship of vegetation indicies to crop condition parameters such as yield. These findings will also be available to the Joint Research and Development Team for use in their continuing research of vegetative indicies.

PREPARED BY:

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TECHNICAL MEMORANDUM NO. 6

RESULTS OF THE VEGETATIVE INDEX CORRELATION STUDY

FOR CROP CONDITION ASSESSMENT PROGRAM

6-TM

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREIGN AGRICULTURAL SERVICE
HOUSTON, TEXAS

NASA-JSC

ABSTRACT

The vegetation index (VI) correlation study was conducted to determine the relationship among the greeness measures computed by seven VI's.

The VI's included in the study were the:

1. Ashburn Vegetative Index (AVI)
2. Difference Vegetative Index (DVI)
3. Green Vegetative Index* (GVI)
4. Kauth Vegetative Index* (KVI)
5. Leaf Vegetative Index (LVI)
6. Perpendicular Vegetative Index (PVI)
7. Transformed Area Index (LAI)

Each of the VI's are transformations derived from the Landsat multispectral scanner (MSS) data. The study used various statistical analyses including correlation analysis and analysis of variance techniques to determine if similarities and differences exist among the greeness measures computed by the VI's. Additionally, the analysis assessed the stability of the VI relationships as a function of crop development.

The results of this study will be used to support a follow-on study designed to determine the relationship of the greeness measures computed by the VI's to crop condition criteria such as plant height, plant density and yield.

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* For purposes of this report the Kauth Vegetative Index (KVI) is equivalent to the Green Number used during the LACIE and the Green Vegetative Index (GVI) is equivalent to the greeness component of the Kauth transform.

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PART 1.0 INTRODUCTION

1.1 BACKGROUND

Agricultural applications of Landsat multispectral scanner (MSS) data have been limited primarily to the measurement of crop area and the data has not been widely used for the purpose of assessing a crop's condition. However, many Landsat data users have felt the MSS data contained information on crop condition and could potentially be useful for detecting, monitoring and assessing abnormal growing conditions affecting crop development and condition. A number of vegetative index (VI) transformations derived from the MSS data have been developed by the research and development community (Exhibit 1, A, B). The VI transformations measure the level of the greeness [1/] of vegetation and therefore provide a good foundation for measuring a crop's condition. During the Large Area Crop Inventory Experiment (LACIE) one such number, the Green Index Number (GIN) was used successfully to detect, monitor and assess drought conditions in the U.S. Great Plains during the 1976 crop year (Exhibit 1, C).

A variety of these VI's exist today, each developed under differing R&D conditions. Each VI is computed by inputting all or a subset of the four Landsat MSS bands into specific transformations. Future efforts to be conducted by the Crop Condition Assessment Division (CCAD) of the Foreign Agricultural Service (FAS) and the Joint R&D Team composed of USDA, NASA and NOAA personnel will determine the relationship between VI's and crop condition parameters, such as crop yield.

1.2 PURPOSE

The purpose of this technical memorandum is to present the results of a study implemented to determine if similarities and differences exist among seven VI's [2/] that include the:

1) Ashburn Vegetative Index (AVI)
2) Difference Vegetative Index (DVI)
3) Green Vegetative Index [3/] (GVI)
4) Kauth Vegetative Index [3/] (KVI)
5) Leaf Area Index (LAI)
6) Perpendicular Vegetative Index (PVI)
7) Transformed Vegetative Index (TVI)

1/ A greeness level is determined by the reflectance measures of all or a subset of the 4 MSS bands depending on the VI calculated. The greeness level increases as the vegetative cover over a given area increases in density.

2/ The VI equations are shown in Appendix A.

3/ For purposes of this report the KVI is equivalent to the Green Number used during the LACIE and the GVI is equivalent to the greeness component of the Kauth transform.

The results obtained from this study will be used to support a follow-on study to be conducted by the CCAD and the Joint R&D Team. This follow-on study will determine if statistically significant relationships exist between VI's and crop condition criteria such as plant height, plant density and yield.

1.3 APPROACH

Five LACIE 5x6 nautical mile blind sites [4/] collected during the 1977 crop year were selected in North Dakota to support the VI correlation study. The seven VI's were computed for a number of spring wheat fields contained in each blind site. Table 1 shows the blind sites, acquisitions and number of spring wheat fields used in the study.

Spring wheat growth stage estimates were obtained from the adjustable crop calendar model developed by the Center for Climatical and Environmental Analysis (CCEA). A growth stage was assigned to each blind site acquisition depending on the location of the blind site relative to the growth stage strata [5/]. All wheat fields within an acquisition were assigned the identical growth stage. Table 2 shows the growth stages assigned to each blind site acquisition. (Refer to Appendix B for interpretation of the growth stage number assignments)

Correlation coefficients were computed for each of the 21 different combinations of the seven VI's (i.e., KVI vs GVI; KVI vs AVI; KVI vs DVI; etc.) across all growth stages and by each growth stage. In this way the effect of time and crop development on the VI correlations could be identified.

A number of statistical tests were performed on the VI correlation coefficients to determine the relationship among the greeness measures computed by the VI transformations.

1.4 SUMMARY AND CONCLUSIONS

The results of this study showed the following:

4/ A LACIE blind site is a 5 x 6 nautical mile sample segment for which ground observed data such as field identifications were collected. Blind site information was used by the LACIE to assess the accuracy of the classification results achieved by the LACIE analysts.

5/ Growth stage strata were determined by spreading the growth stage estimates obtained at each of a number of meteorological stations in North Dakota over the entire state and then grouping areas within the state bearing the same growth stage.

A. The level of correlation of a VI combination (e.g., LAI vs KVI, AVI vs GVI, ..., PVI vs TVI) is relatively stable over time. Those VI's showing the least level of correlation coefficient stability were the DVI vs LAI, KVI vs LAI, GVI vs DVI, GVI vs LAI, AVI vs LAI and PVI vs LAI. In these cases the standard deviation of the correlation coefficients was slightly higher than the other VI combination categories.

B. The level of correlation of those growth stages tested was relatively stable across all VI combinations. Those growth stages showing the least level of correlation coefficient stability were growth stages 3.7, 4.3 and 5.3. Reasons for these differences could not be explained due to a lack of detailed ground truth information.

C. The LAI, TVI and DVI measures of greeness were different when compared to each other and when compared to the greeness measures of the KVI, GVI, PVI, and AVI. The KVI, GVI, PVI and AVI measured greeness similarly and anyone of these VI's would have yielded a similar measure of greeness.

1.5 FUTURE PLANS

The results of this study indicated that differences exist among the greeness measures of four of the seven VI's. Four of the VI's will be included in the follow-on study which will determine the relationship of the VI's to crop condition parameters. The four VI's to be included in the follow-on study include the LAI, TVI, DVI and one of the following; KVI, GVI, PVI or AVI.

The study will be conducted over a number of blind sites located in North Dakota and Montana. The field data to be used in the study was collected for winter and spring wheat during the 1978 growing year. Elements of the field data consist of plant height, plant density, growth stage and yield observations. VI's will be computed from the 5 x 6 nautical mile LACIE blind sites for each field. Statistical techniques including regression analysis will be used to determine the relationship of the Landsat data to crop calendar, crop yield and general crop condition.

Those VI/crop condition relationships found to be strongly correlated and predictive will be operationally implemented by the CCAD during 1979.

PART 2.0 RESULTS OF TESTS

2.1 TEST OF SIGNIFICANCE OF VI CORRELATIONS ACROSS ALL GROWTH STAGES

This test was performed to determine the stability of the correlation between two VI's over time. Table 3 shows the correlation coefficients by growth stage for each of 21 VI combinations. The means (μ) and standard deviations (σ) of the correlaton coefficients are also shown at the bottom of table 3. Confidence intervals were computed for each VI combination at the .05 and .10 levels of significance. The asterisk and double asterisks above the correlation coefficients mark those growth stages which were significantly different at the .05 and .10 levels of significance, respectively.

Any correlation coefficient marked by an asterisk is signficantly different from the sample population. In this case, the sample population included the correlation coefficient of a VI combination at each growth stage. For example, the KVI vs GVI sample population included the correlation coefficients by growth stage starting at growth stage 1.3 and concluding with the "all" growth stages category, (i.e., 1.00, 0.99 1.00, 1.00, 1.00, 1.00 . . . 0.97, 0.99). The "all" growth stages category was the result of combining all the growth stage data into a single category.

The level of correlation of a VI combination was relatively stable over time. Those VI combinations which showed the least level of correlation coefficient stability were the DVI vs LAI, KVI vs LAI, GVI vs DVI, GVI vs LAI, AVI vs LAI, and PVI vs LAI. In these cases the standard deviation of the correlation coefficients was slightly higher than the other VI combination categories.

Appendix C contains plots showing the relationship between the correlation coefficient and growth stage for the 21 VI combination categories.

2.2 TEST OF SIGNIFICANCE OF VI CORRELATIONS BY GROWTH STAGE

This test was performed to determine the stability of the correlation coefficients for the 21 VI combination categories at a given growth stage. Table 4 shows the correlation coefficients by VI combination for each of 20 growth stage categories. The means and standard deviations of the correlation coefficients are shown at the bottom of table 4. Confidence intervals were computed for each growth stage at the .05 and .10 levels of significance. The asterisk and double asterisks above the correlation coefficents mark those VI combination categories which were significantly different at the .05 and .10 levels of significance, respectively.

Any correlation coefficient marked by an asterisk was significantly different from the sample population. The sample population included the correlation coefficients for each VI combination category within a growth stage. For example, the correlation coefficients within growth stage 1.3 included those 21 VI combination categories starting with the KVI vs GVI category and concluding with the TVI vs LAI category (i.e., 1.00, 0.97, 0.99, ..., 0.97, 0.99). The "all" growth stages category was the result of combining all the growth stage data into a single category.

The level of correlation within any growth stage including the "all" growth stages category was relatively stable across all VI combination categories. Those growth stages which showed the least level of correlation coefficient stability were growth stages 3.7, 4.3, and 5.3. The standard deviation of the correlation coefficients was slightly higher in these categories when compared to the other growth stage categories. Reasons for these differences could not be determined due to a lack of detailed ground truth information.

Appendix D contains plots showing the relationship between the correlation coefficients and the VI combination categories for the 20 growth stages.

2.3 RELATIONSHIP AMONG VI'S

2.3.1 Background

Reiterating, the purpose of each of the VI's is to measure the greeness of vegetation. However, do significant differences exist with the greeness measures computed by these VI's? If not, a single VI would provide all the information about greeness that the other six would provide in combination, or independently. Only a subset of the seven VI's may prove to be significantly different from one another, while the others contain no more information than the separable subset. For example, three of the seven VI's may be significantly different from one another, while each of the remaining four are similar to one or more of the three significantly different VI's.

One way analysis of variance tests were performed on the correlation coefficients of each VI combination category formed for a given VI in an effort to answer the above question. Six different groups were defined for each VI (each combination is defined as a group). Each group contained the correlation coefficients at each growth stage for a given VI combination.

2.3.2 LAI vs other VI's

Table 5 shows the 6 groups formed when testing if significant

differences exist among the correlation coefficients for the 6 LAI/VI combinations. The test results indicated that significant differences (at .10 level of significance) do not exist among the correlation coefficients for the 6 groups. However, the grand mean for the 6 groups was .953 which indicated that although there were not significant differences among the correlation coefficients for the 6 groups there were consistent differences among the greeness measures of the LAI and the other VI's. If the grand mean were higher (i.e., between .975-1.00) and the one way analysis of variance test found the correlation coefficients to be statistically equlivalent then one could conclude that each VI measures greeness similarly. The correlation coefficient grand mean computed for the six LAI groups was too low to unmistakenly conclude that each of the seven VI's compute greeness similarly.

2.3.3 GVI vs other VI's

Test results for the GVI versus the other 6 VI's indicated that significant differences did exist among the correlation coefficients for the 6 groups. Table 6 shows the correlation coefficient means, standard deviations and grand mean for the 6 GVI groups. The grand mean increased from .976 to .983 by deleting the GVI vs LAI group from the other 5 groups. In addition the test results became significant which indicated that the correlation coefficients for the remaining 5 groups were not significantly different from one another. The test results indicated dissimilarity between the LAI and GVI. Therefore the LAI and GVI yield different measures of greeness.

2.3.4 KVI vs other VI's

Test results for the KVI versus the other 6 VI's indicated that significant differences did exist among the correlation coefficients for the 6 groups. Table 7 shows the correlation coefficient means, standard deviations, and grand mean for the 6 KVI groups. The grand mean increased from .976 to .985 by deleting the KVI vs LAI and KVI vs TVI groups. In addition the test results became significant which indicated that the correlation coefficients for the remaining 4 groups were not significantly different from one another. The test results indicated the LAI and TVI yield different measures of greeness when compared to the KVI. The test results remained insignificant by deleting the KVI vs LAI group and the KVI vs TVI group separately from the other groups.

2.3.5 AVI vs other VI's

Test results for the AVI were similar to those obtained for the GVI. The test results for the AVI versus the other 6 VI's

indicated that significant differences did exist among the correlation coefficients for the 6 groups. Table 8 shows the correlation coefficient means, standard deviations and grand mean for the 6 AVI groups. The grand mean increased from .977 to .983 by deleting the AVI vs LAI group from the other 5 groups. Additionally the test results became significant which indicated that the correlation coefficients for the remaining 5 groups were not significantly different from one another. The test results indicated dissimilarity between the greeness measures of the LAI and AVI.

2.3.6 PVI vs other VI's

Test results for the PVI were similar to those obtained for the GVI and AVI. Test results for the PVI versus the other 6 VI's indicated that significant differences did exist among the correlation coefficients for the 6 groups. Table 9 shows the correlation coefficient means, standard deviations and grand mean for the 6 PVI groups. The grand mean increased from .979 to .984 by deleting the PVI vs LAI group from the other 5 groups. In addition the test results became significant which indicated that the correlation coefficients for the remaining 5 groups were not significantly different from one another. The PVI vs TVI group yielded a correlation coefficient mean of .97 and a standard deviation of .03 but did not prove to be significantly different from the other 4 groups.

In this case one would conclude that the LAI and the PVI are dissimilar, and therefore would yield different measures of greeness.

2.3.7 TVI vs other VI's

Test results for the TVI were similar to those obtained for the LAI. The results indicated that there were not significant differences among the correlation coefficients for the 6 TVI groups. Table 10 shows the correlation coefficient means, standard deviations and grand mean for the 6 TVI groups. However, the grand mean for the 6 groups was .968 which indicated that although there were not any significant differences among the correlation coefficients for the 6 groups there were consistent differences between the TVI and the other VI's. The TVI vs AVI group yielded a somewhat larger correlation coefficient ($r = .98$) when compared to the other groups, but was not found to be significantly different.

The test results indicated the measure of greeness computed by the TVI is different when compared to the greeness measures computed by the other VI's.

2.3.8 DVI vs other VI's

Test results for the DVI indicated that there were not significant differences among the correlation coefficients for

the 6 DVI groups. Table 11 shows the correlation coefficient means, standard deviations and grand mean for the 6 DVI groups. However, the grand mean for 6 groups was .970 which indicated that although there were not any significant differences among the correlation coefficients for the 6 groups there were consistent differences between the DVI and the other VI's. The DVI vs LAI group yielded a lower correlation coefficient (r =.94) when compared to the other groups but was not found to be insignificant. The standard deviation of the correlation coefficients for each of the 6 groups was relatively high which caused this test to be comparatively more permissive than the other tests.

In this case the measure of greeness computed by the DVI is different when compared to the greeness measures computed by the other VI's.

TABLE 1

BLIND SITES, ACQUISITIONS AND NUMBER OF FIELDS USED IN THE STUDY

BLIND SITE	ACQUISITIONS (JULIAN DATE)	# OF FIELDS
1619	77122, 77140, 77158, 77175, 77212	15
1640	77121, 77140, 77175, 77193, 77211	14
1663	77121, 77139, 77157, 77175, 77193 77211	15
1913	77125, 77143, 77161, 77179, 77197 77215	15
1927	77121, 77140, 77158, 77175, 77193	12

TABLE 2

GROWTH STAGE ESTIMATES FOR EACH BLIND SITE ACQUISITION

BLIND SITE	ACQUISITION (JULIAN DATE)	GROWTH STAGE
1619	77122	1.6
	77140	2.7
	77158	3.5
	77175	4.3
	77212	5.9
1640	77121	1.5
	77140	2.6
	77175	4.4
	77193	5.4
	77211	6.0
1663	77121	1.3
	77138	2.4
	77157	3.6
	77175	4.3
	77193	5.3
	77211	6.0
1913	77125	2.2
	77143	2.8
	77161	3.7
	77179	4.6
	77197	5.2
	77215	6.0
1927	77121	1.8
	77140	2.8
	77158	3.7
	77175	4.3
	77193	5.4

TABLE 3

TEST OF SIGNIFICANCE OF VI CORRELATIONS ACROSS ALL GROWTH STAGES

GROWTH STAGE	VI COMBINATIONS																			
	K-G	K-A	K-D	K-P	K-T	K-L	G-A	G-D	G-P	G-T	G-L	A-D	A-P	A-T	A-L	D-P	D-T	D-L	P-T	P-L	T-L
1.3	1.00	0.97	0.99	0.98	0.96	0.96	0.96	0.98	0.99	0.96	0.96	0.98	0.97**	0.98	0.87**	0.99	0.98	0.93	0.95	0.93	0.89*
1.6	0.99	0.97	0.98	0.97	0.94	0.95	0.96	0.97	0.96	0.92	0.94	0.99	0.97**	0.96	0.90	0.98	0.97	0.94	0.97	0.97	0.95
1.8	1.00	0.99	0.92	0.97	0.98	0.90	0.99	0.92	0.97	0.98	0.90	0.92**	0.98	0.98	0.93	0.93	0.94	0.86**	0.97	0.94	0.94
2.2	1.00	0.96**	0.97	0.99	0.94	0.99	0.96	0.97	0.98	0.90**	0.99	0.99	0.98	0.99	0.94	0.99	0.99	0.96	0.97	0.97	0.92**
2.4	1.00	1.00	1.00	1.00	0.99	0.98	1.00	1.00	1.00	0.99	0.98	1.00	1.00	0.99	0.99	1.00	0.99	0.98	0.99	0.98	1.00
2.6	1.00	0.99	1.00	1.00	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	1.00	1.00	0.99	0.99	0.99	0.99	1.00
2.7	1.00	0.99	0.99	1.00	0.98	0.97	1.00	1.00	1.00	0.99	0.98	1.00	1.00	0.99	0.98	1.00	0.99	0.98	0.99	0.98	0.99
2.8	0.99	0.99	0.99	0.99	0.97	0.97	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.99	0.99	1.00	0.99	0.99	0.99	0.99	1.00
3.5	1.00	0.99	0.99	0.99	0.96	0.90	0.99	0.99	0.99	0.96	0.90	1.00	1.00	0.97	0.88**	1.00	0.97	0.88	0.97	0.89	0.91*
3.6	0.99	0.99	0.99	0.99	0.95	0.94	1.00	1.00	1.00	0.96	0.94	1.00	1.00	0.96	0.95	1.00	0.96	0.94	0.96	0.95	0.98
3.7	1.00	1.00	0.83*	1.00	0.99	0.99	1.00	0.83*	1.00	0.99	0.99	0.82*	1.00	0.99	0.99	0.82*	0.83*	0.85**	0.99	0.99	0.99
4.3	1.00	0.98	0.98	0.98	0.89*	0.81*	0.99	0.99	0.99	0.92	0.84*	1.00	1.00	0.91*	0.82*	1.00	0.90**	0.80*	0.90*	0.80*	0.96
4.4	1.00	0.99	0.99	0.99	0.95	0.94	0.99	0.99	0.99	0.96	0.95	1.00	1.00	0.96	0.95	1.00	0.96	0.95	0.96	0.95	0.98
4.6	1.00	1.00	1.00	1.00	0.98	0.98	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.98	0.98	1.00	0.98	0.98	0.98	0.98	1.00
5.2	0.99	0.99	1.00	1.00	0.99	0.98	1.00	1.00	1.00	0.99	0.98	1.00	1.00	0.99	0.98	1.00	0.99	0.98	0.99	0.98	1.00
5.3	0.99	0.96**	0.91**	0.91*	0.91*	0.86*	0.92*	0.85*	0.85*	0.87*	0.81*	0.97	0.97	0.97	0.93	1.00	0.98	0.98	0.90*	0.88**	0.98
5.4	1.00	1.00	1.00	1.00	0.98	0.98	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.99	0.99	1.00	0.98	0.99	0.99	0.99	1.00
5.9	1.00	0.99	1.00	1.00	0.98	0.99	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.99	0.99	1.00	0.99	0.99	0.98	0.99	0.99
6.0	0.97*	0.97	0.99	1.00	0.96	0.95	1.00	1.00	0.99	0.99	0.99	0.99	1.00	0.99	0.99	1.00	0.99	0.98	0.98	0.98	0.99
ALL	0.99	0.99	0.98	0.99	0.96	0.97	0.99	0.99	1.00	0.98	0.98	0.99	0.99	0.98	0.97	0.99	0.97	0.97	0.98	0.97	0.99
μ	1.00	0.99	0.98	0.99	0.96	0.95	0.99	0.97	0.99	0.97	0.95	0.98	0.99	0.98	0.95	0.99	0.97	0.94	0.97	0.96	0.97
σ	0.01	0.01	0.04	0.02	0.03	0.05	0.02	0.05	0.03	0.04	0.05	0.04	0.01	0.02	0.05	0.04	0.04	0.06	0.03	0.05	0.03

*Significantly different at the .05 level of significance
**Significantly different at the .10 level of significance

TABLE 4

TEST OF SIGNIFICANCE OF VI CORRELATIONS BY GROWTH STAGE

	GROWTH STAGES																			
VIN VS. VIN	ALL	1.3	1.6	1.8	2.2	2.4	2.6	2.7	2.8	3.5	3.6	3.7	4.3	4.4	4.6	5.2	5.3	5.4	5.9	6.0
KVI/GVI	0.99	1.00	0.99	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.99	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.97
KVI/AVI	0.99	0.97	0.97	0.99	0.96	1.00	0.99	0.99	0.99	0.99	0.99	1.00	0.98	0.99	1.00	0.99	0.96	1.00	0.94	0.97
KVI/DVI	0.98	0.99	0.98	0.92	0.97	1.00	1.00	0.99	0.99	0.99	0.99	0.83**	0.98	0.99	1.00	1.00	0.91	1.00	1.00	0.99
KVI/PVI	0.99	0.98	0.97	0.97	0.99	1.00	1.00	1.00	0.99	0.99	0.99	1.00	0.98	0.99	1.00	1.00	0.91	1.00	1.00	0.99
KVI/TVI	0.96**	0.96	0.94	0.98	0.94	0.99	0.99	0.98	0.97**	0.96	0.95	0.99	0.89	0.95	0.98	0.99	0.91	0.98	0.99	0.96
KVI/LAI	0.97	0.96	0.95	0.90	0.99	0.98	1.00	0.97**	0.97**	0.90	0.94	0.99	0.81**	0.94**	0.98	0.98	0.86	0.98	0.99	0.95*
GVI/AVI	0.99	0.96	0.96	0.99	0.96	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.99	0.99	1.00	1.00	0.92	1.00	1.00	1.00
GVI/DVI	0.99	0.98	0.97	0.92	0.97	1.00	1.00	1.00	1.00	0.99	1.00	0.83**	0.99	0.99	1.00	1.00	0.85	1.00	1.00	1.00
GVI/PVI	1.00	0.99	0.96	0.97	0.98	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.99	0.99	1.00	1.00	0.85	1.00	1.00	0.99
GVI/TVI	0.98	0.96	0.92**	0.98	0.90*	0.99	0.99	0.99	0.99	0.96	0.96	0.99	0.92	0.96	0.99	0.99	0.87	0.99	0.99	0.99
GVI/LAI	0.99	0.96	0.94	0.90	0.99	0.98	1.00	0.98	0.99	0.90	0.94	0.99	0.84	0.95	0.99	0.98	0.81*	0.99	0.99	0.99
AVI/DVI	0.99	0.98	0.99	0.92	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.82**	1.00	1.00	1.00	1.00	0.97	1.00	1.00	0.99
AVI/PVI	0.99	0.97	0.97	0.98	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	1.00	1.00	0.99
AVI/TVI	0.98	0.98	0.96	0.98	0.99	0.99	0.99	0.99	0.99	0.97	0.96	0.99	0.91	0.96	0.98	0.99	0.97	0.99	0.99	0.99
AVI/LAI	0.97	0.87*	0.90*	0.93	0.94	0.99	1.00	0.98	0.99	0.88**	0.95	0.99	0.82**	0.95	0.98	0.98	0.93	0.99	0.99	0.99
DVI/PVI	0.99	0.99	0.98	0.93	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.82**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DVI/TVI	0.97	0.98	0.97	0.94	0.99	0.99	0.99	0.99	0.99	0.97	0.96	0.83**	0.90	0.96	0.98	0.99	0.98	0.98	0.99	0.99
DVI/LAI	0.97	0.93	0.94	0.86*	0.96	0.98	0.99	0.98	0.99	0.88**	0.94	0.85	0.80**	0.95	0.98	0.98	0.88	0.99	0.99	0.98
PVI/TVI	0.98	0.95	0.97	0.97	0.97	0.99	0.99	0.99	0.99	0.97	0.96	0.99	0.90	0.96	0.98	0.99	0.90	0.99	0.98**	0.98
PVI/LAI	0.97	0.93	0.97	0.94	0.97	0.98	0.99	0.98	0.99	0.89**	0.95	0.99	0.80**	0.95	0.98	0.98	0.88	0.99	0.99	0.98
TVI/LAI	0.99	0.89*	0.95	0.94	0.92**	1.00	1.00	0.99	1.00	0.91	0.98	0.99	0.96	0.98	1.00	1.00	0.98	1.00	0.99	0.99
μ	0.98	0.96	0.96	0.95	0.97	0.99	1.00	0.99	0.99	0.96	0.97	0.95	0.93	0.97	0.99	0.99	0.92	0.99	0.99	0.98
σ	0.01	0.03	0.02	0.04	0.03	0.01	0.00	0.01	0.01	0.04	0.02	0.08	0.07	0.02	0.01	0.01	0.05	0.01	0.01	0.01

*Significantly different at the .05 level of significance
**Significantly different at the .10 level of significance

TABLE 5

CORRELATION COEFFICIENT VS. GROWTH STAGE
FOR EACH OF 6 LAI/VI COMBINATIONS

GROWTH STAGE	LAI/KVI	LAI/GVI	LAI/AVI	LAI/DVI	LAI/PVI	LAI/TVI
1.3	.97	.99	.97	.97	.97	.99
1.6	.96	.96	.87	.93	.93	.89
1.8	.95	.94	.90	.94	.97	.95
2.2	.90	.90	.93	.86	.94	.94
2.4	.99	.99	.94	.96	.97	.92
2.6	.98	.98	.99	.98	.98	1.00
2.7	1.00	1.00	1.00	.99	.99	1.00
2.8	.97	.98	.98	.98	.98	.99
3.5	.97	.99	.99	.99	.99	1.00
3.6	.90	.90	.86	.86	.89	.91
3.7	.94	.94	.95	.94	.95	.96
4.3	.95	.99	.99	.85	.99	.99
4.4	.81	.84	.82	.80	.80	.96
4.6	.94	.95	.95	.95	.95	.98
5.2	.98	.99	.98	.98	.98	1.00
5.3	.98	.98	.98	.98	.98	1.00
5.4	.86	.81	.93	.88	.88	.98
5.9	.96	.99	.99	.99	.99	1.00
6.0	.99	.99	.99	.99	.99	.99
ALL	.95	.99	.99	.98	.98	.99
μ	.95	.95	.95	.94	.96	.97

Grand mean = .953

TABLE 6

CORRELATION COEFFICIENT MEANS, STANDARD DEVIATIONS
AND GRAND MEAN FOR THE 6 GVI VS VI GROUPS

	GVI-KVI	GVI-AVI	GVI-DVI	GVI-PVI	GVI-TVI	GVI-LAI
Mean	1.00	.99	.97	.99	.97	.95
Std. Dev.	.01	.02	.05	.03	.04	.05
GRAND MEAN	.976					

TABLE 7

CORRELATION COEFFICIENT MEANS, STANDARD DEVIATIONS
AND GRAND MEAN FOR THE 6 KVI VS VI GROUPS

	KVI-GVI	KVI-AVI	KVI-DVI	KVI-PVI	KVI-TVI	KVI-LAI
Mean	1.00	.99	.98	.99	.96	.95
Std. Dev.	.01	.01	.04	.02	.03	.05
GRAND MEAN	.976					

TABLE 8

CORRELATION COEFFICIENT MEANS, STANDARD DEVIATIONS
AND GRAND MEAN FOR THE 6 AVI VS VI GROUPS

	AVI-KVI	AVI-GVI	AVI-DVI	AVI-PVI	AVI-TVI	AVI-LAI
Mean	.99	.99	.98	.99	.98	.95
Std. Dev.	.01	.02	.04	.01	.02	.05
GRAND MEAN	.977					

TABLE 9

CORRELATION COEFFICIENT MEANS, STANDARD DEVIATIONS
AND GRAND MEAN FOR THE 6 PVI VS VI GROUPS

	PVI-KVI	PVI-GVI	PVI-AVI	PVI-DVI	PVI-TVI	PVI-LAI
Mean	.99	.99	.99	.99	.97	.96
Std. Dev.	.02	.03	.01	.04	.03	.05
GRAND MEAN	.979					

TABLE 10

CORRELATION COEFFICIENT MEANS, STANDARD DEVIATIONS AND GRAND MEAN FOR THE 6 TVI VS VI GROUPS

	TVI-KVI	TVI-GVI	TVI-AVI	TVI-DVI	TVI-PVI	TVI-LAI
Mean	.96	.97	.98	.97	.97	.97
Std. Dev.	.03	.04	.02	.04	.03	.03
GRAND MEAN	.968					

TABLE 11

CORRELATION COEFFICIENT MEANS, STANDARD DEVIATIONS AND GRAND MEAN FOR THE 6 DVI VS VI GROUPS

	DVI-KVI	DVI-GVI	DVI-AVI	DVI-PVI	DVI TVI	DVI-LAI
Mean	.98	.97	.98	.99	.97	.94
Std. Dev.	.04	.05	.04	.04	.04	.06
GRAND MEAN	.970					

REFERENCES

A. Ashburn, P. 1978. The Vegetative Index Number and Crop Identification. USDA/FAS/Crop Condition Assessment Division. (to be published)

B. Richardson, A.J., and C.L. Wiegand. 1977. Distingushing Vegetation from Soil Background Information. Photogrammetric Engineering and Remote Sensing 43(12): 1541 - 1552.

C. Thompson, D.R., and O.A. Wehmanen. 1978. Detecting and Monitoring Agricultural Vegetative Water Stress Over Large Areas Using Landsat Digital Data. NASA/JSC-13737; LACIE-00506. 24 pp.

APPENDIX A

Vegetative Index Transformations

$$AVI = 2CH4^{*} - CH2$$

$$DVI = 2.4CH4 - CH2$$

$$TVI = \sqrt{\frac{(CH4 - CH2)}{(CH4 + CH2)} + 0.5}$$

$$PVI = \sqrt{(.355CH4 - .149CH2)^2 + (.355CH2 - .852CH4)^2}$$

$$LAI = \frac{41.325CH1}{CH2} - \frac{42.45CH1}{CH3}$$

$$GVI = -.283CH1 - .660CH2 + .577CH3 + .388CH4$$

$$KVI = GVI - \text{Soil Line}$$

* CH1 = Channel 1 = MSS Band 4
CH2 = Channel 2 = MSS Band 5
CH3 = Channel 3 = MSS Band 6
CH4 = Channel 4 = MSS Band 7

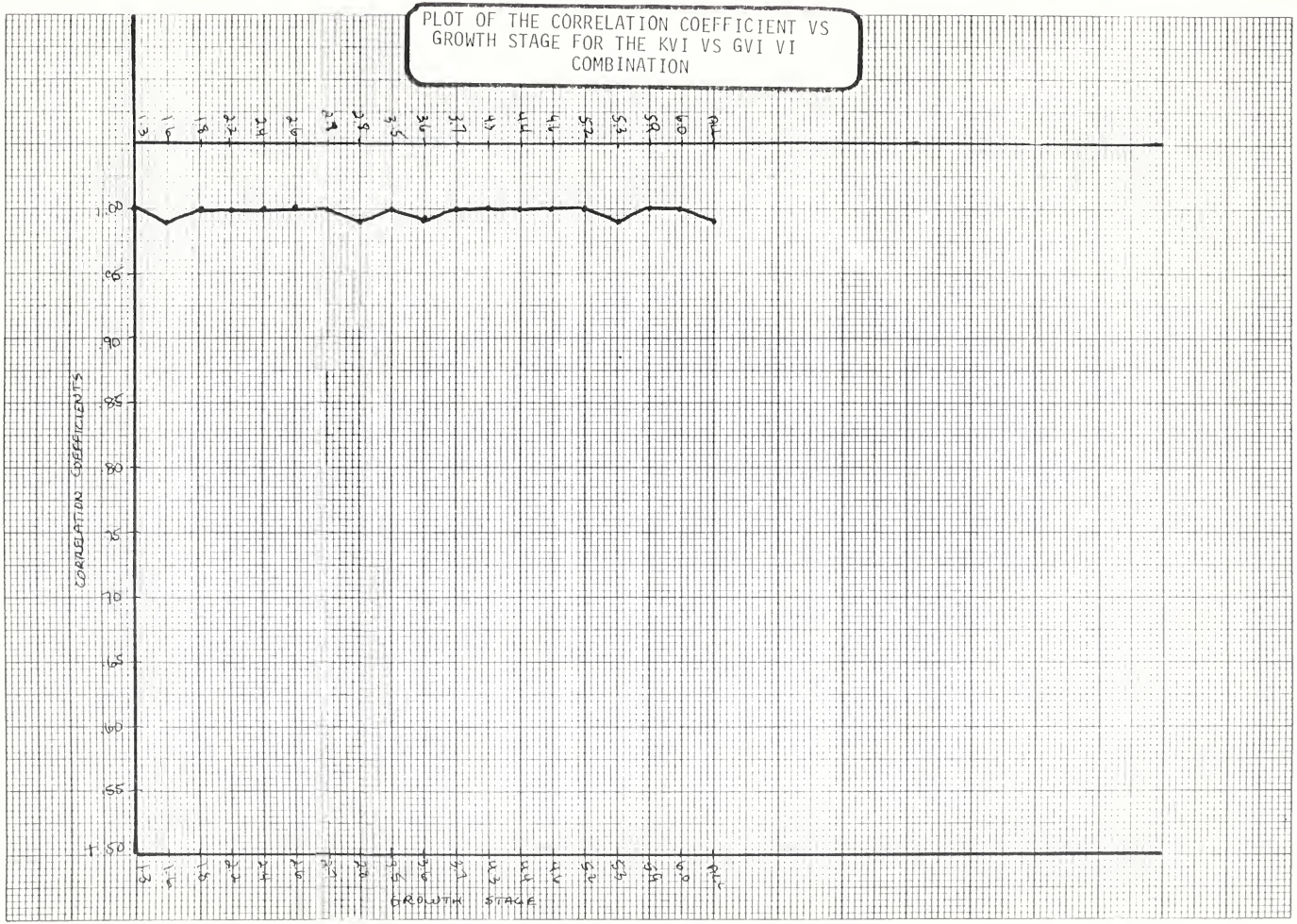
APPENDIX B

GROWTH STAGE*	EVENT
1	Planting
2	Emergence
3	Jointing
4	Heading
5	Soft Dough
6	Hard Dough/Ripe
7	Harvest

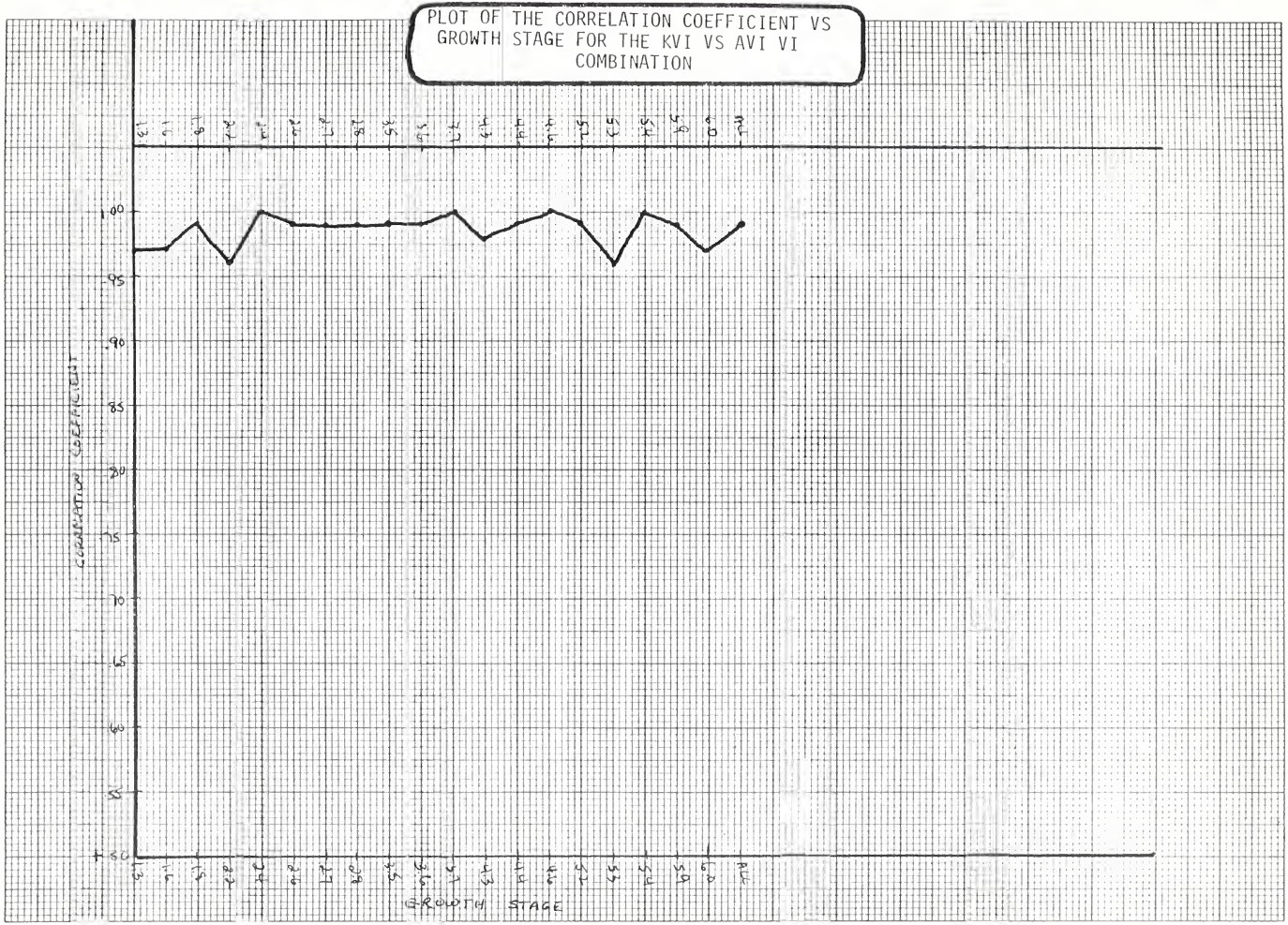
* The wheat crop is at a particular growth stage when 50% of the crops in a given area have reached that particular growth stage.

APPENDIX C

LIST OF FIGURES


PLOT OF THE CORRELATION COEFFICIENT VS GROWTH STAGE FOR THE KVI VS GVI VI COMBINATION
CORRELATION COEFFICIENTS
GROWTH STAGE

FEB 9 1979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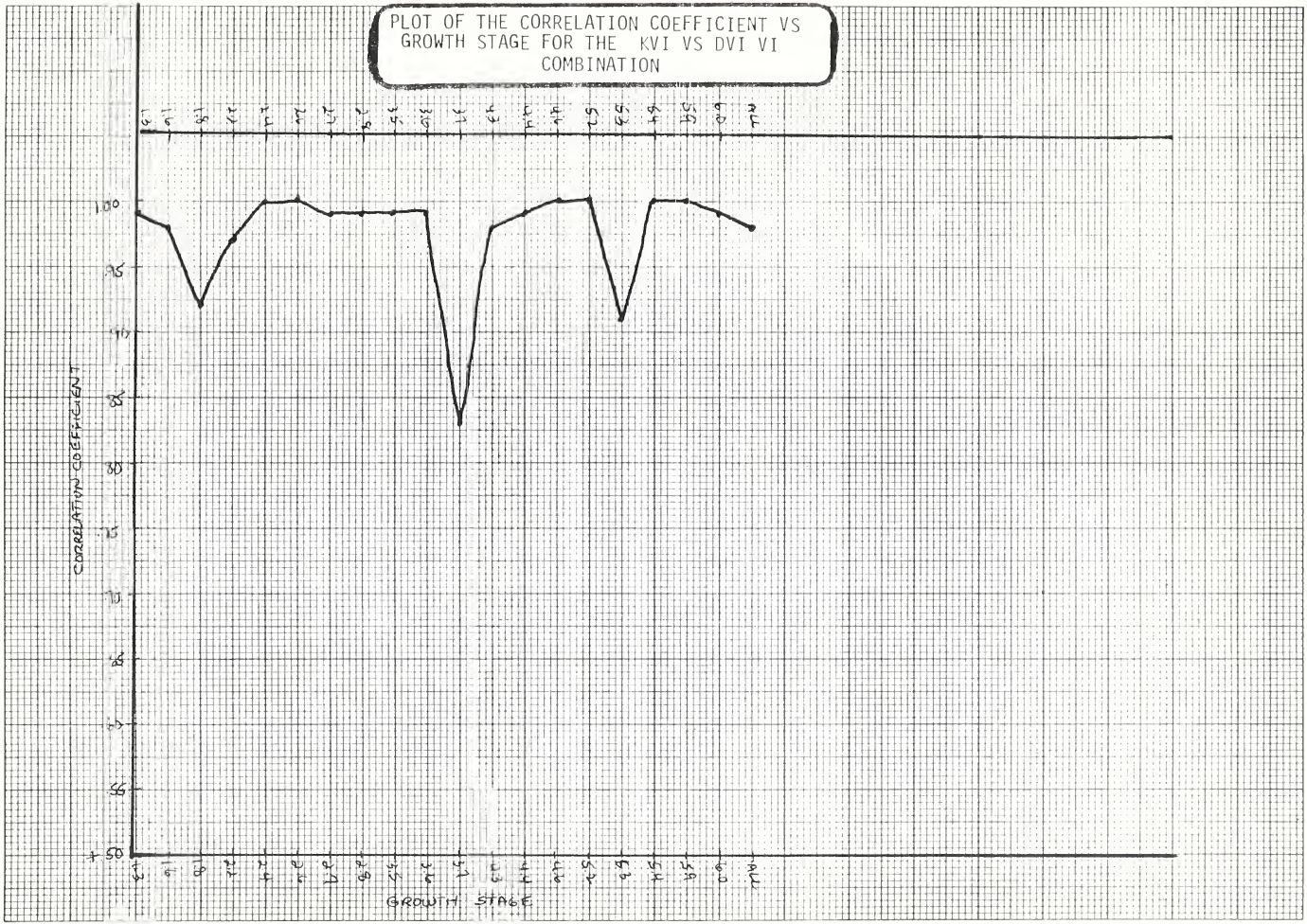
CORRELATION COEFFICIENT
GROWTH STAGE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CORRELATION COEFFICIENT
GROWTH STAGE

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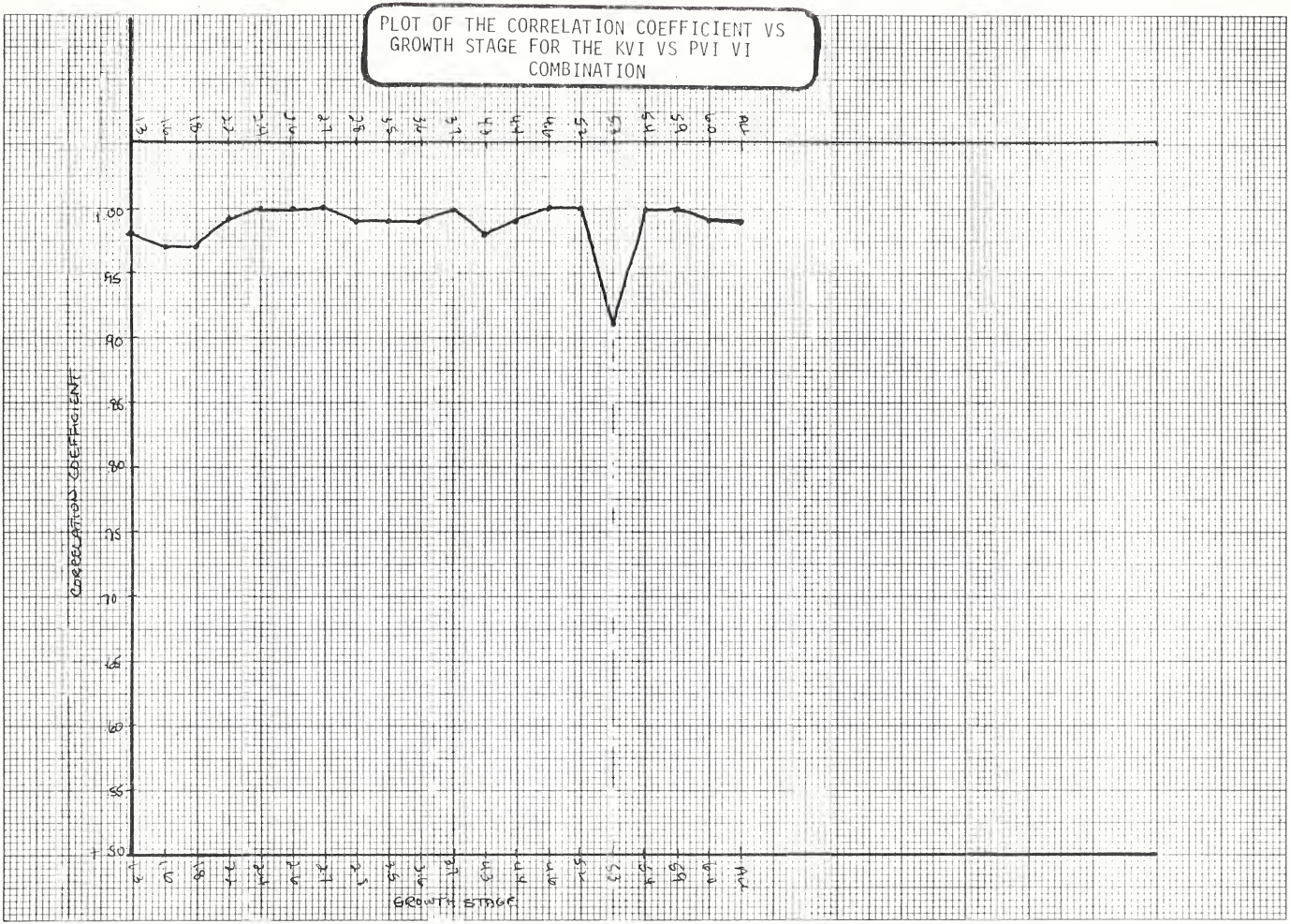
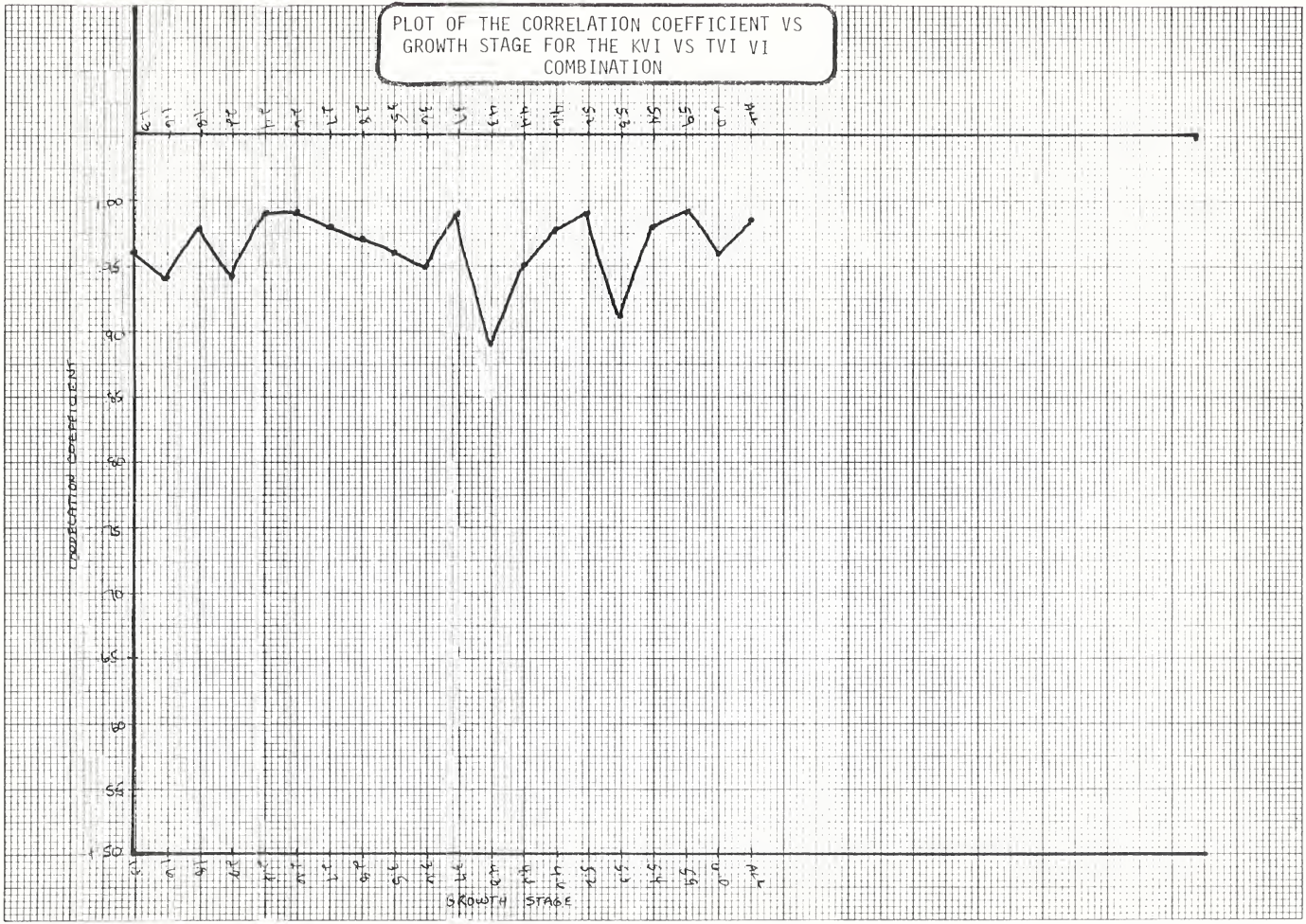

PLOT OF THE CORRELATION COEFFICIENT VS GROWTH STAGE FOR THE KVI VS PVI VI COMBINATION
CORRELATION COEFFICIENT
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50
GROWTH STAGE
1.3
1.8
2.2
2.6
2.7
2.8
3.5
3.7
4.3
4.4
4.6
5.2
5.3
5.4
5.9
6.0
ALL

FEB 9 1979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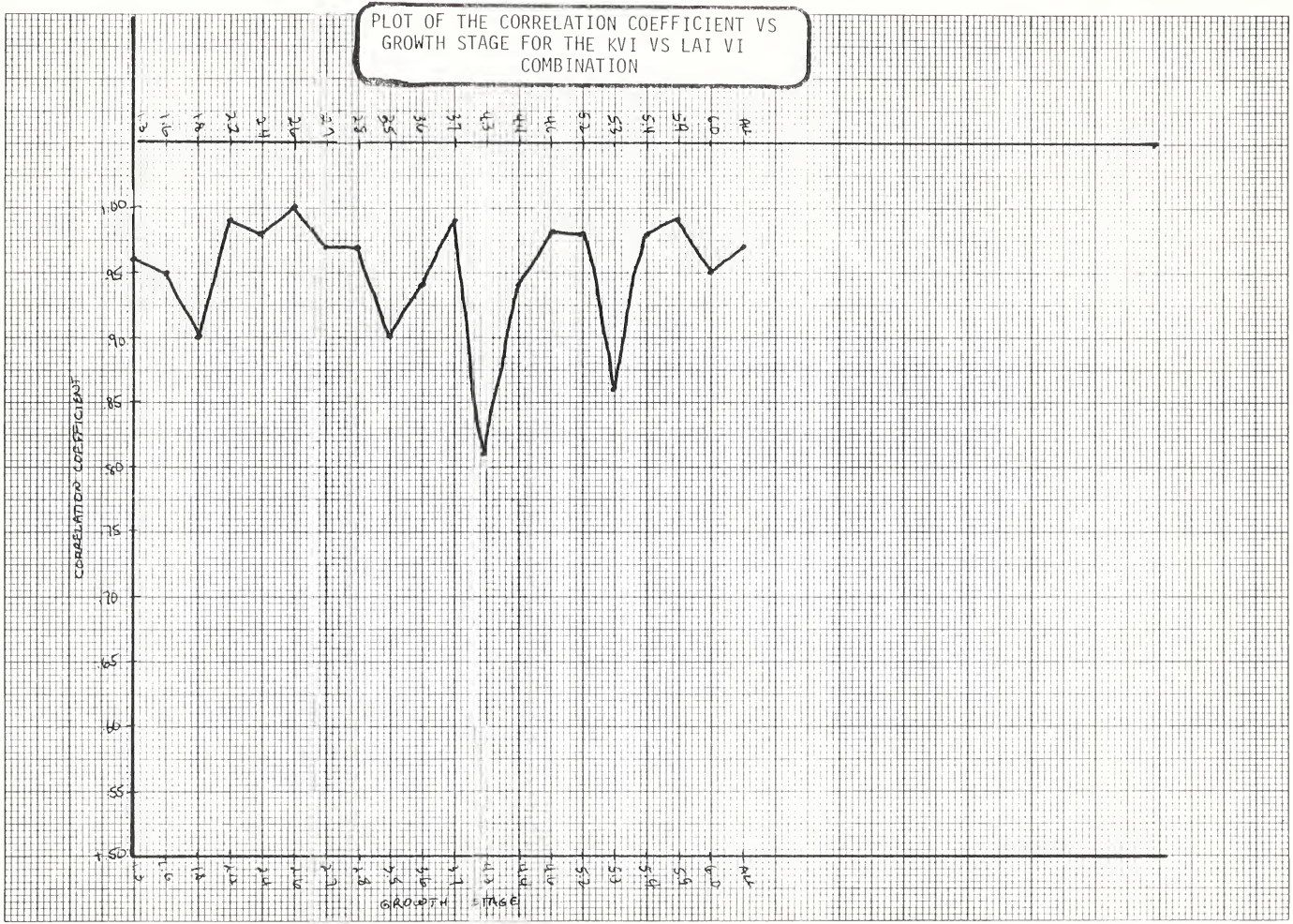
CORRELATION COEFFICIENT
GROWTH STAGE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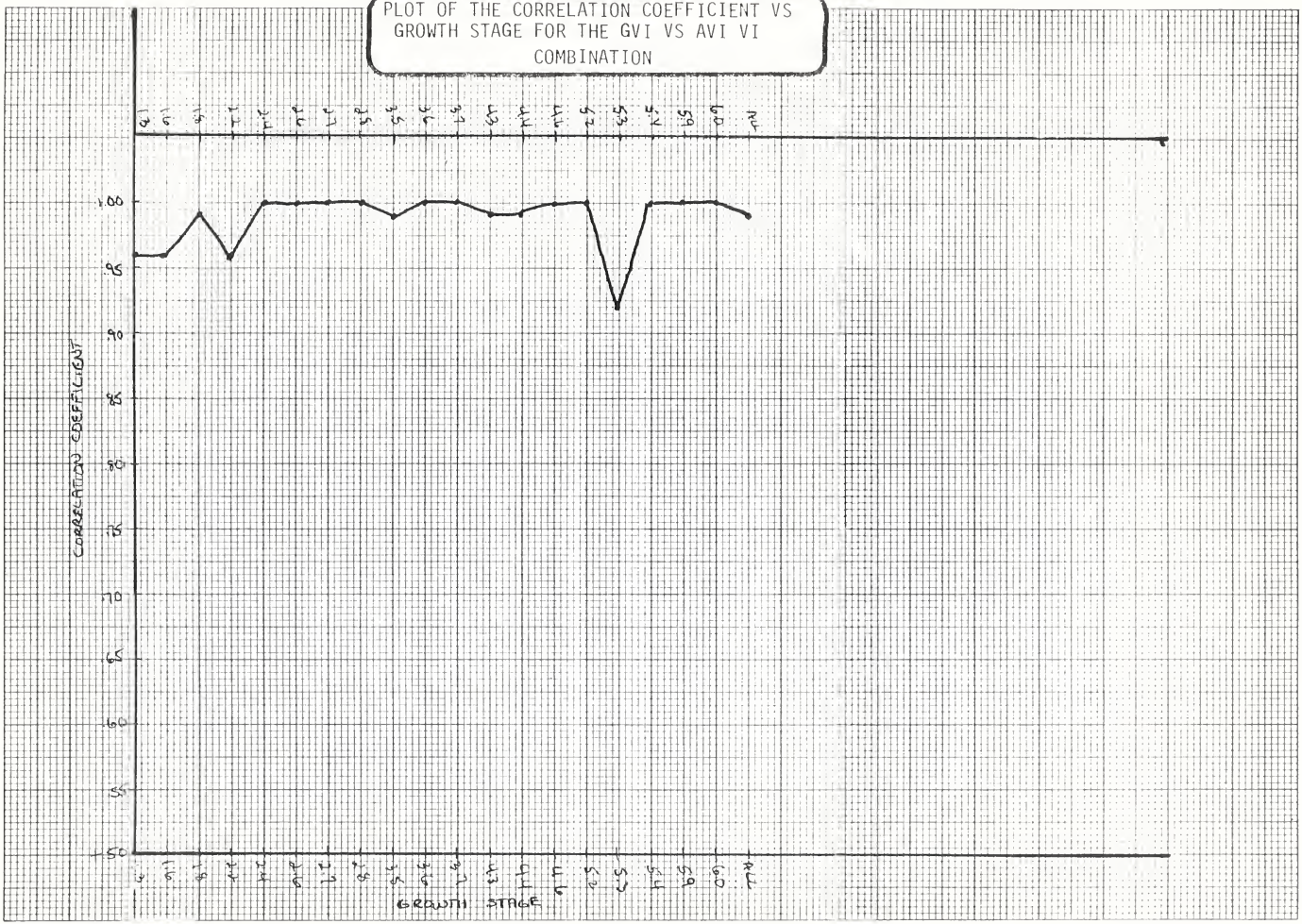
CORRELATION COEFFICIENT
GROWTH STAGE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CORRELATION COEFFICIENT
GROWTH STAGE

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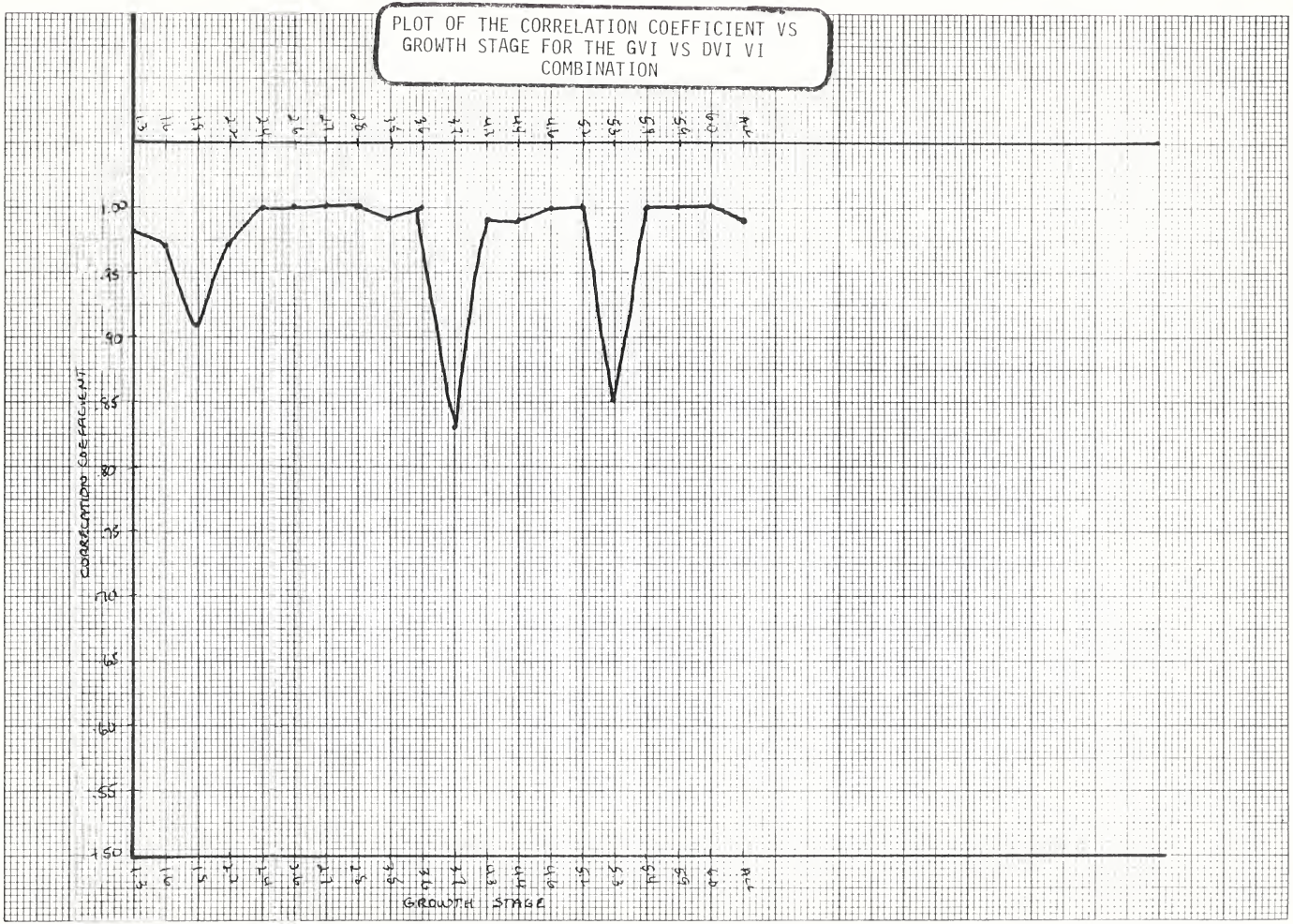
PLOT OF THE CORRELATION COEFFICIENT VS GROWTH STAGE FOR THE GVI VS DVI VI COMBINATION
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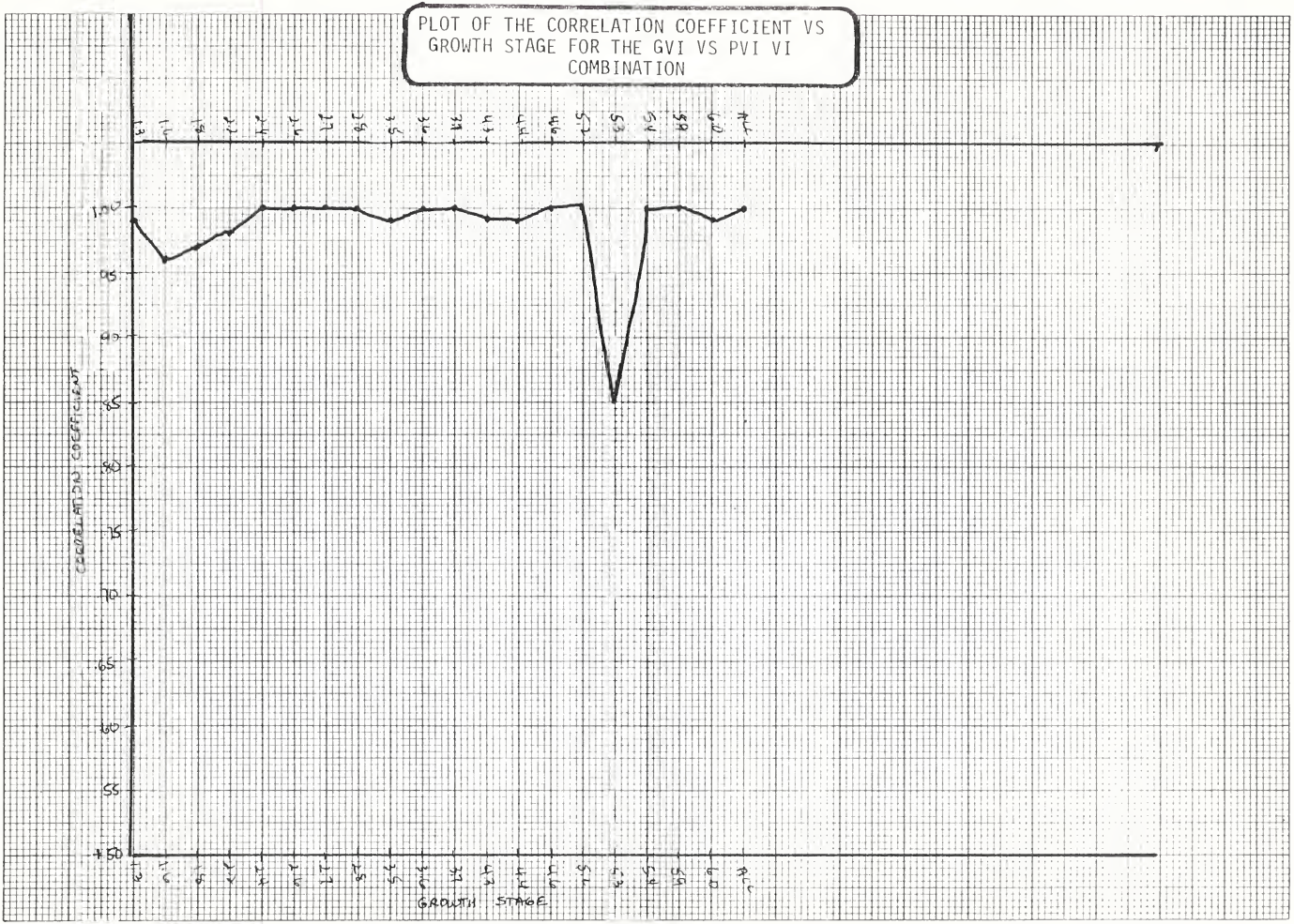
.85
.80
.75
.70
.65
.60
.55
.50

FEB 9 1979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CORRELATION COEFFICIENT
GROWTH STAGE

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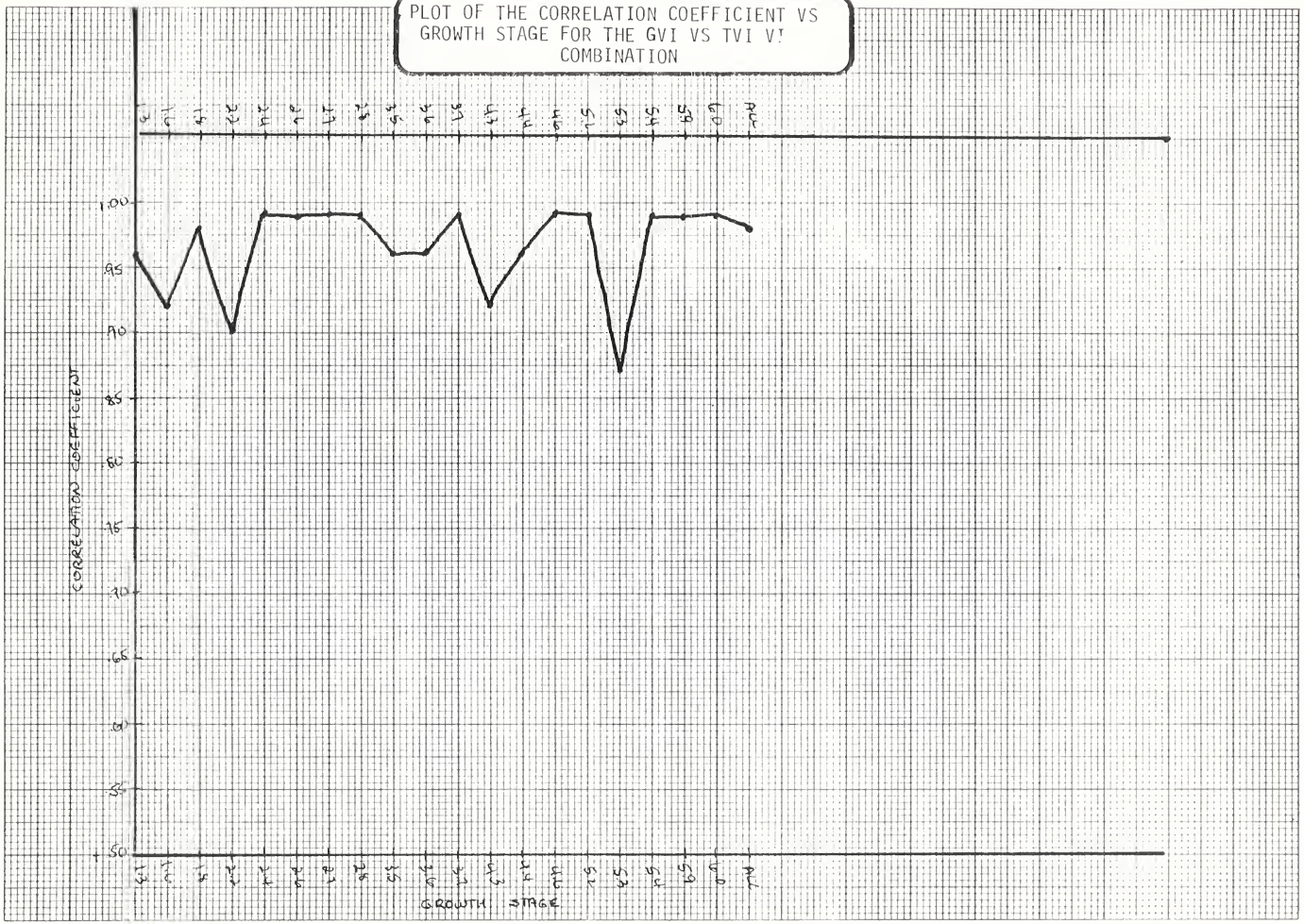
PLOT OF THE CORRELATION COEFFICIENT VS GROWTH STAGE FOR THE GVI VS TVI V!
COMBINATION
CORRELATION COEFFICIENT
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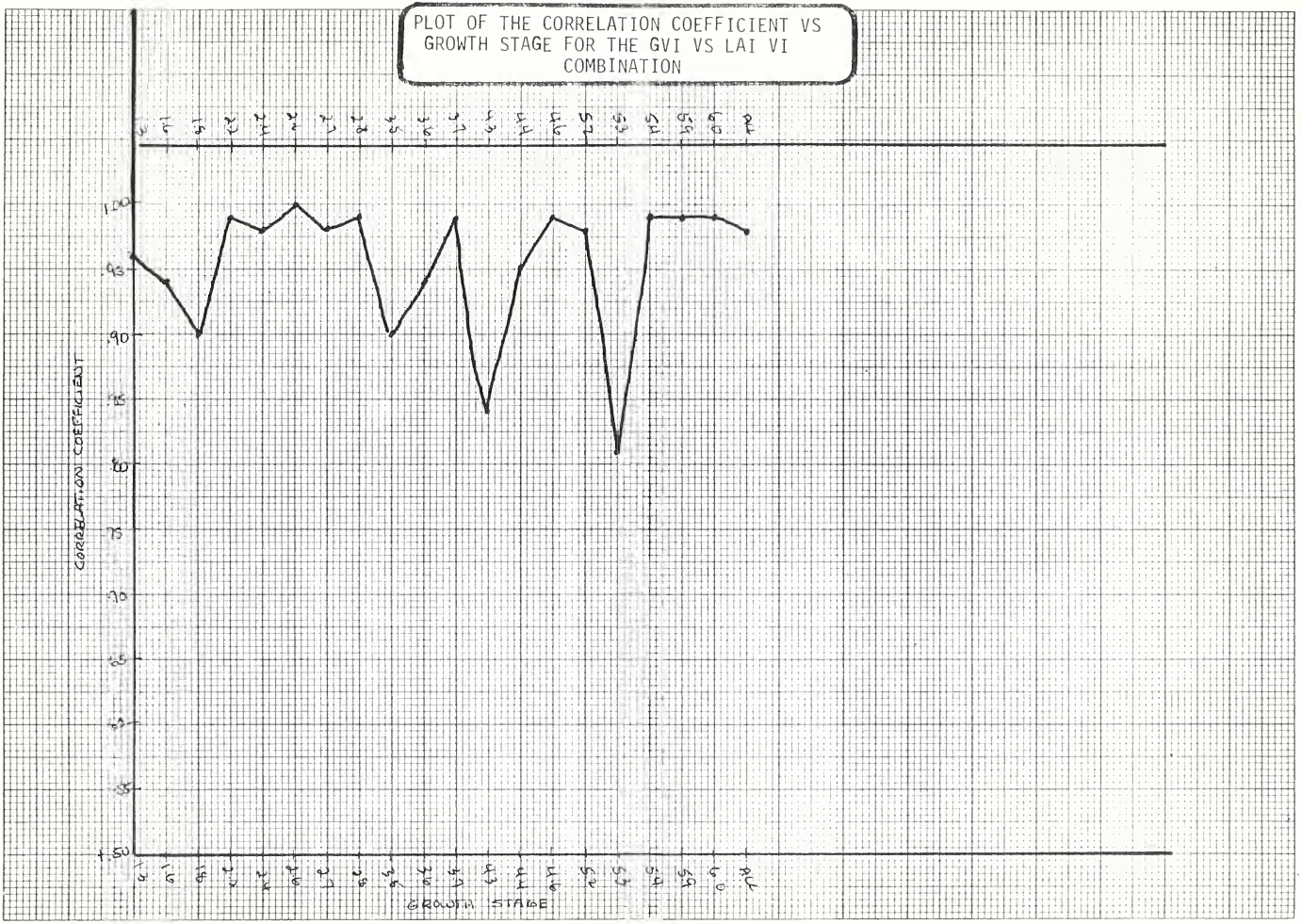
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50
GROWTH STAGE

FEB 9 1979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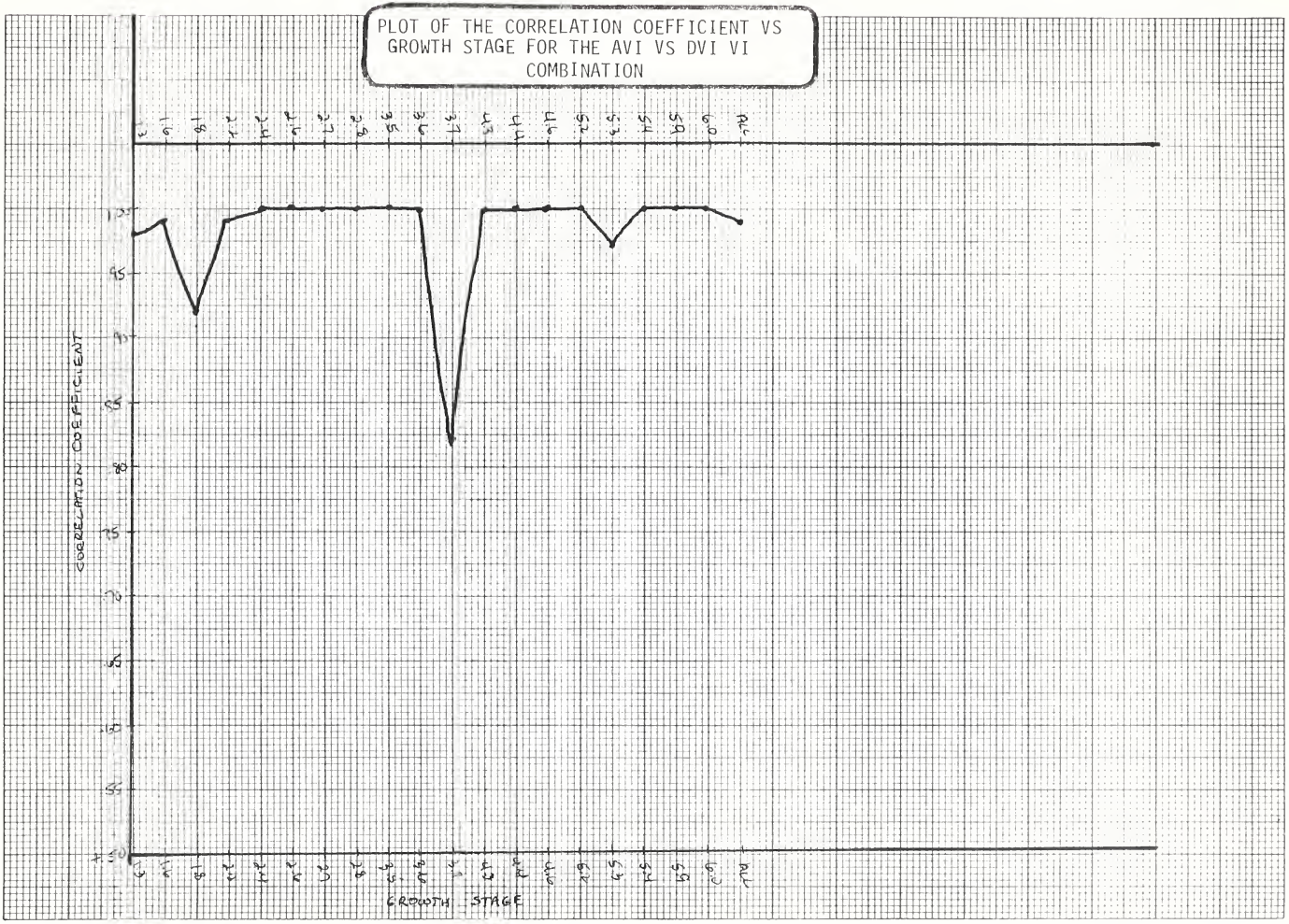
GROWTH STAGE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GROWTH STAGE

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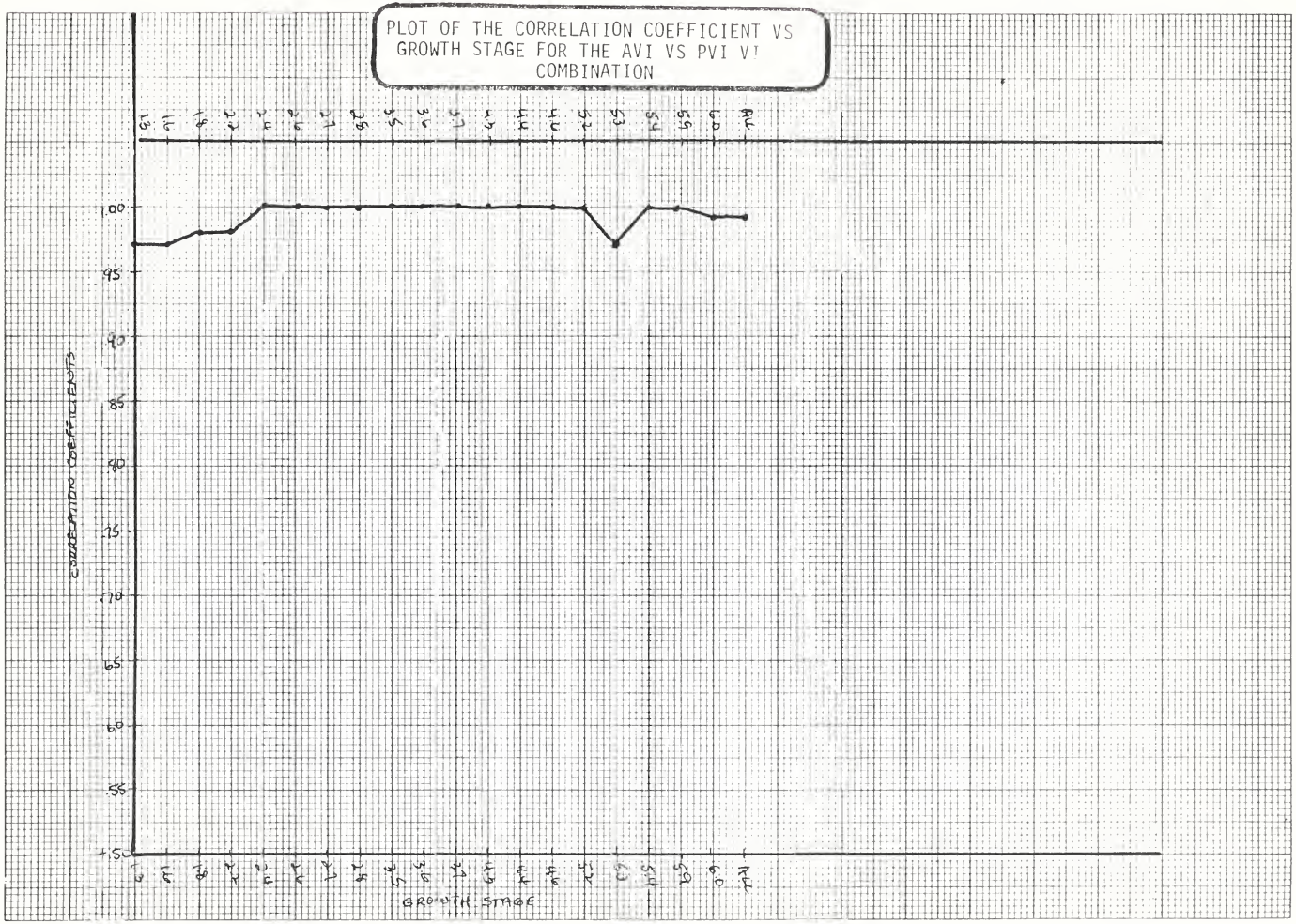
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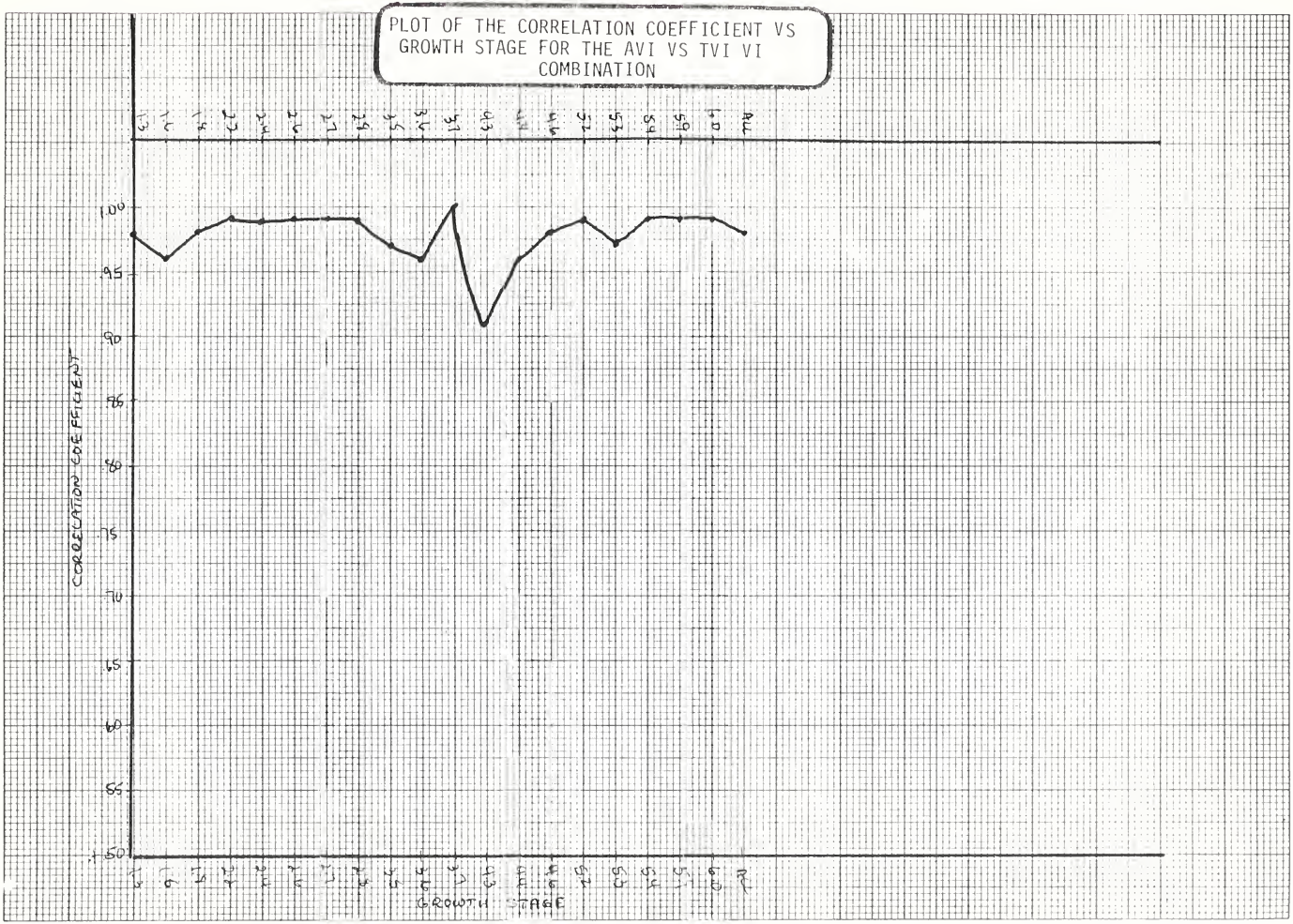
.90
.85
.80
.75
.70
.65
.60
.55
.50

FEB 9 1979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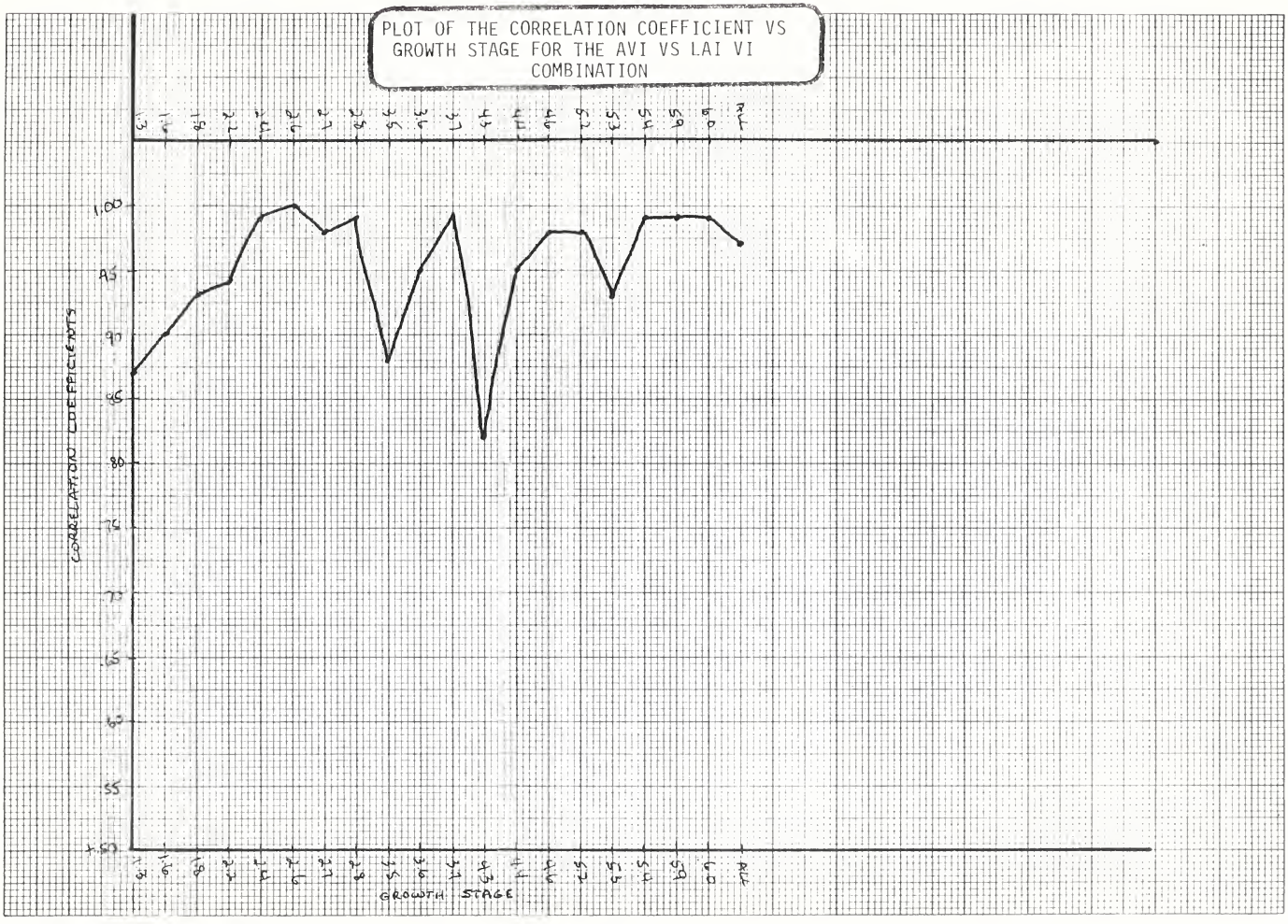
GROWTH STAGE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CORRELATION COEFFICIENTS
GROWTH STAGE

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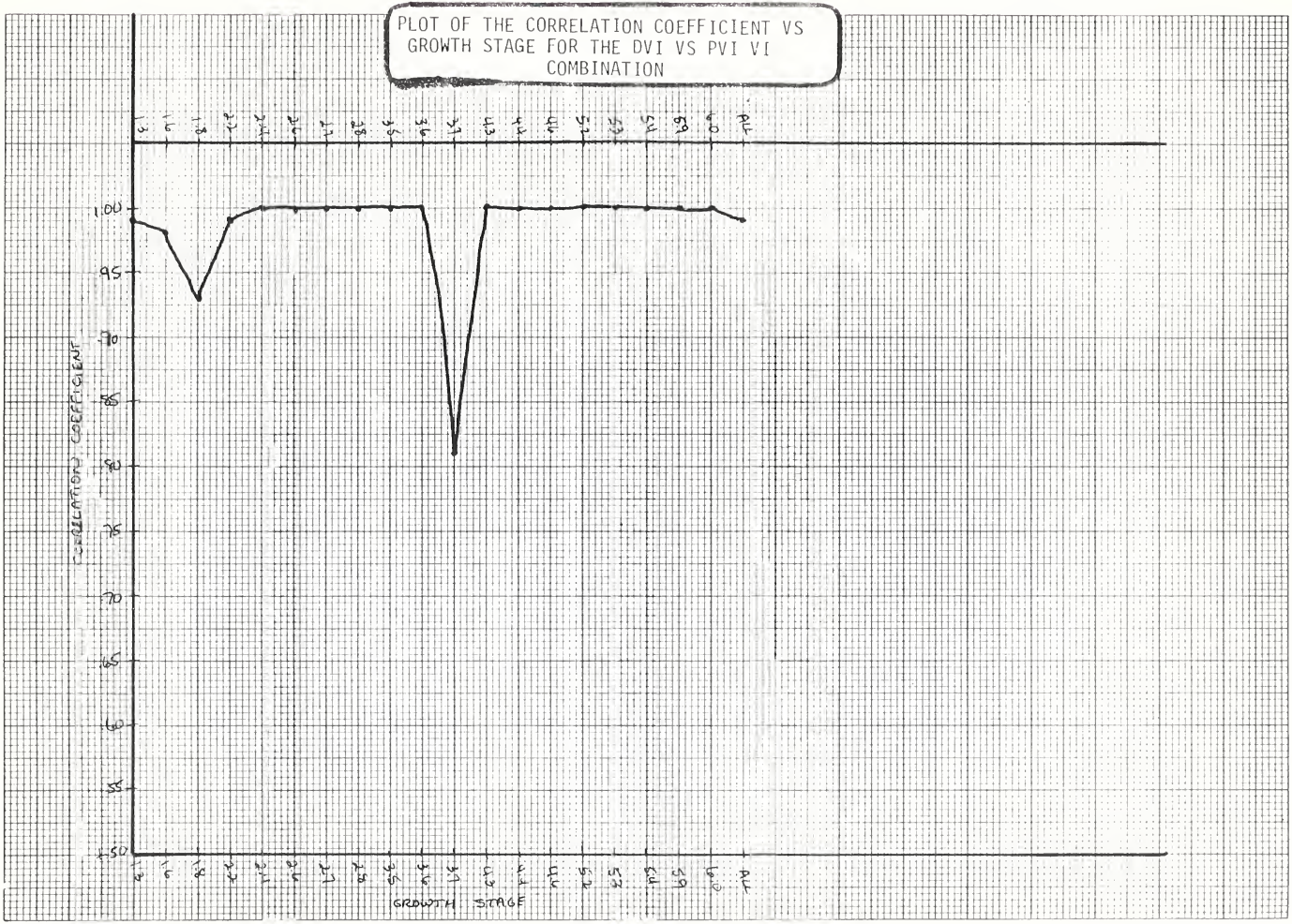
PLOT OF THE CORRELATION COEFFICIENT VS GROWTH STAGE FOR THE DVI VS PVI VI COMBINATION
CORRELATION COEFFICIENT
1.00
95
90
85
80
75
70
65
60
55
50
1.3
1.6
1.8
2.2
2.4
2.6
2.7
2.8
3.5
3.6
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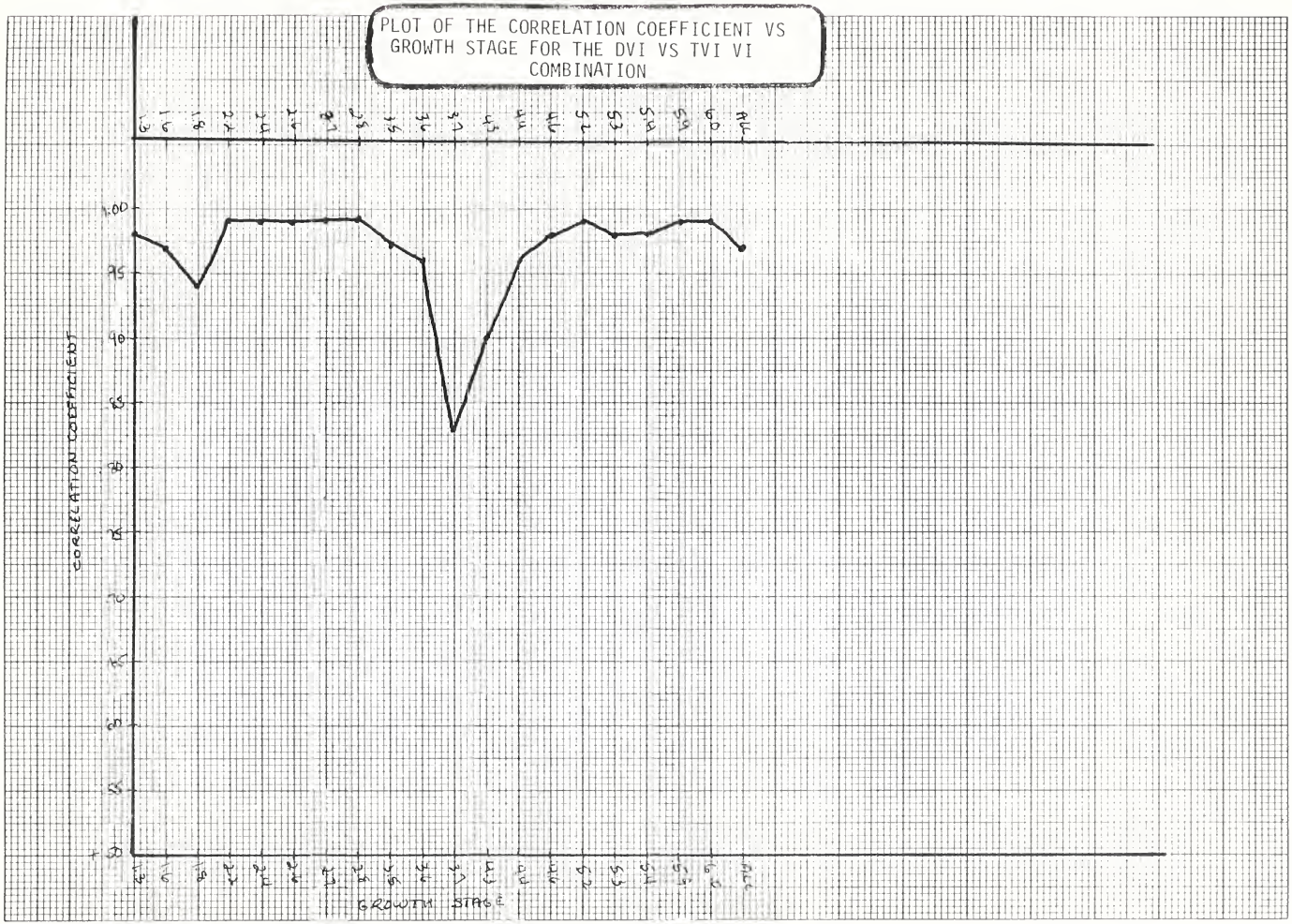
5.8
5.9
6.0
ALL
GROWTH STAGE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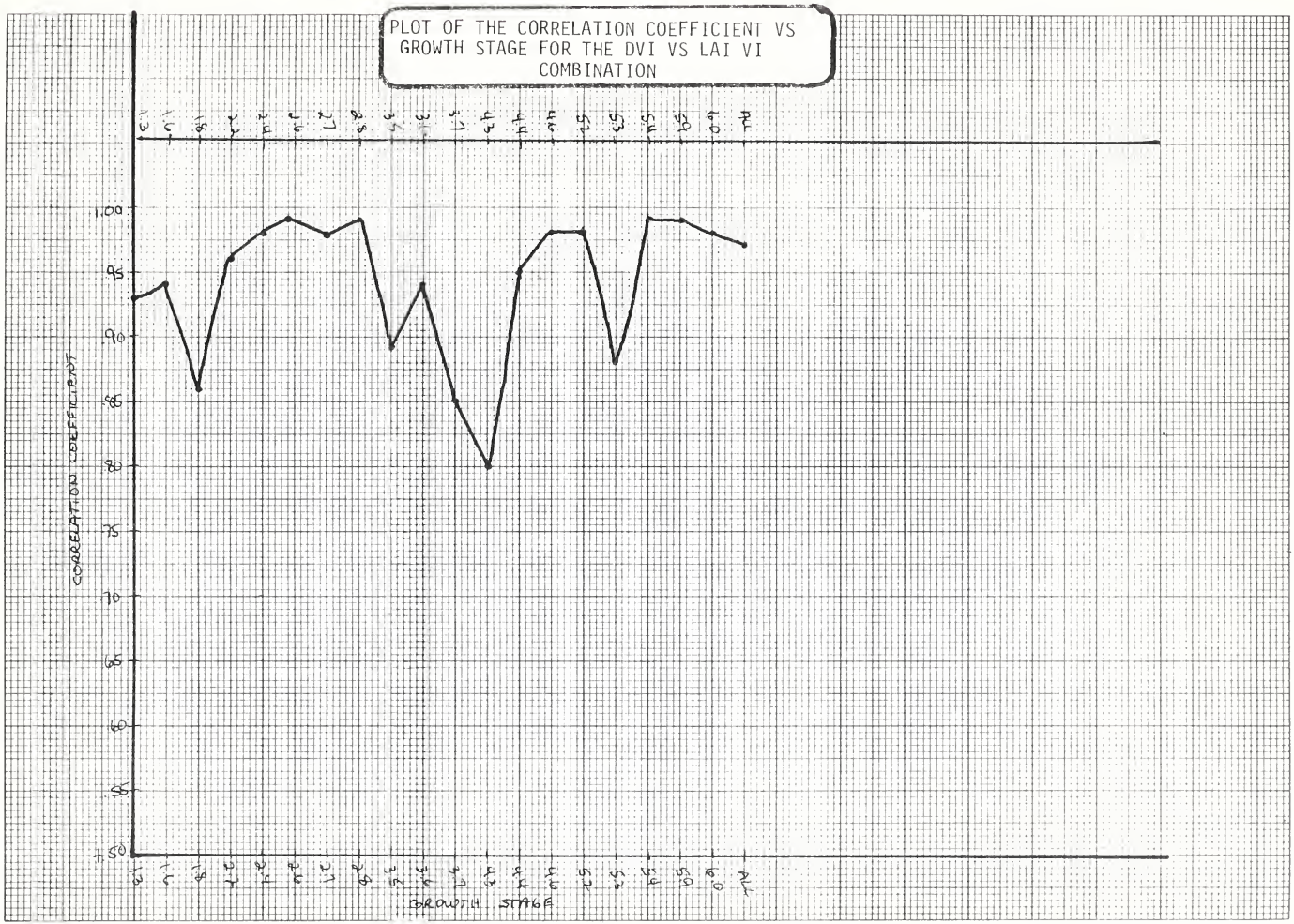
GROWTH STAGE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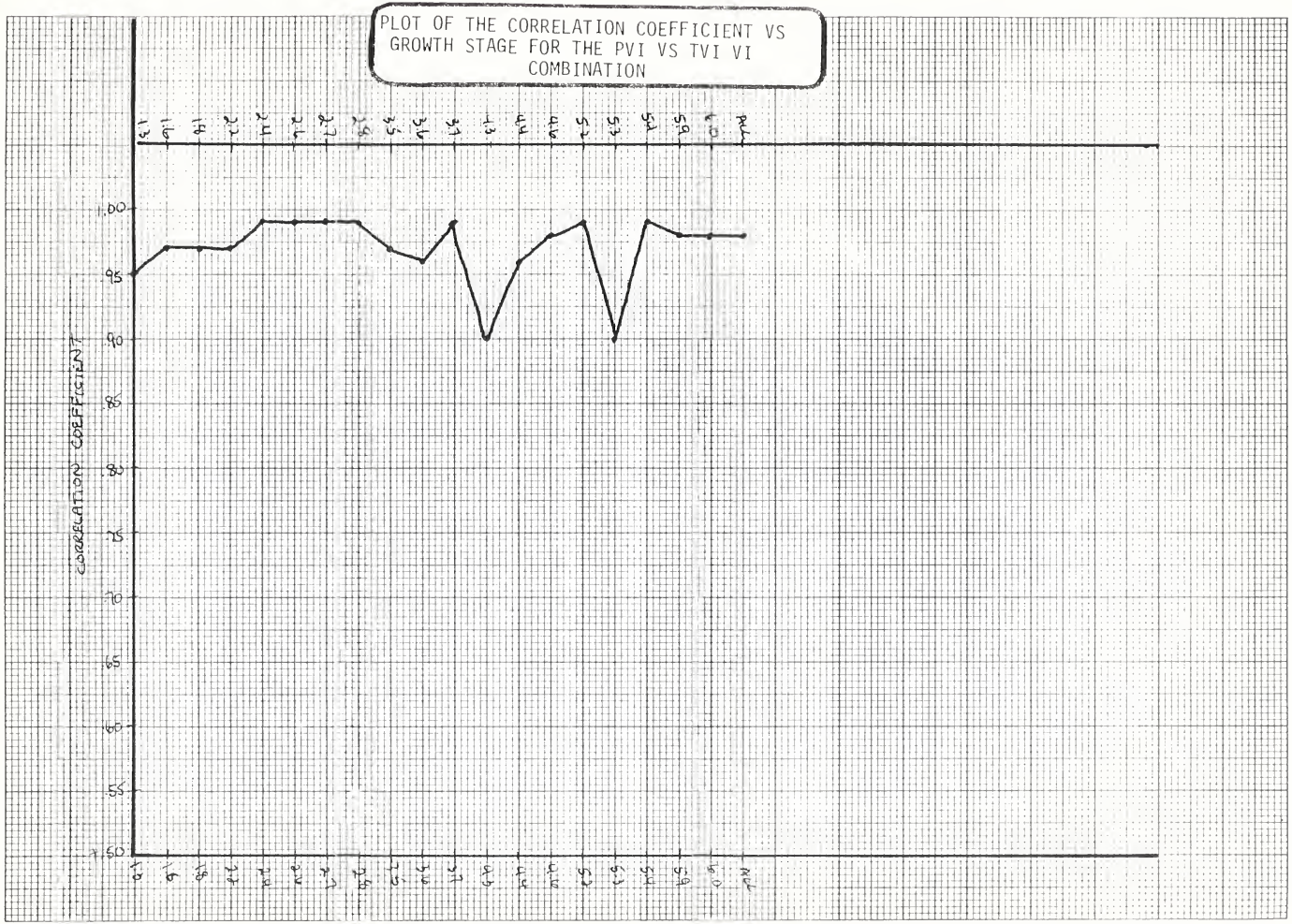
CORRELATION COEFFICIENT
GROWTH STAGE


PLOT OF THE CORRELATION COEFFICIENT VS GROWTH STAGE FOR THE PVI VS TVI VI COMBINATION
CORRELATION COEFFICIENT
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.80
.75
.70
.65
.60
.55
.50
1.3
1.6
1.8
2.2
2.4
2.6
2.7
2.8
3.5
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6.0
PKL

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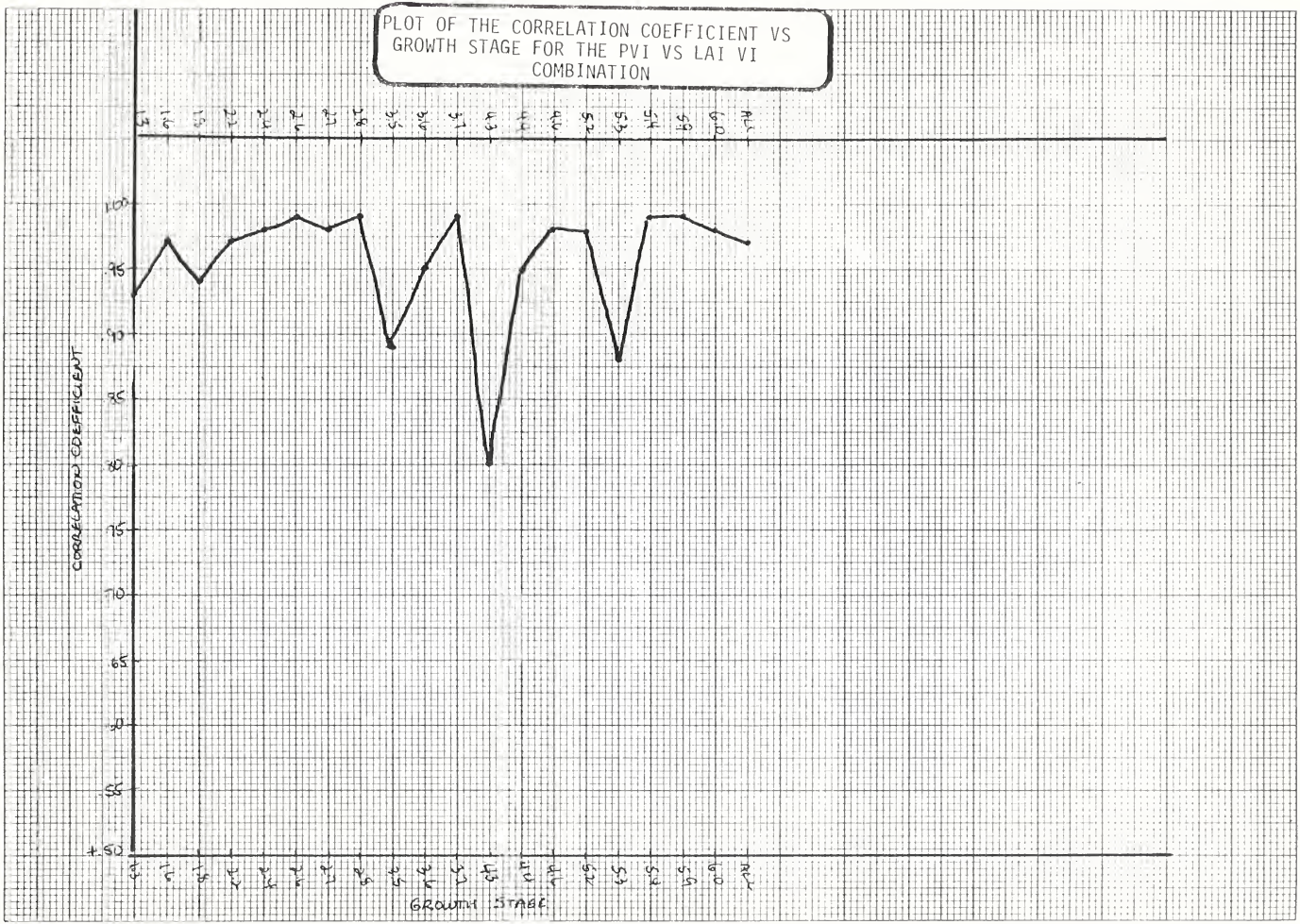
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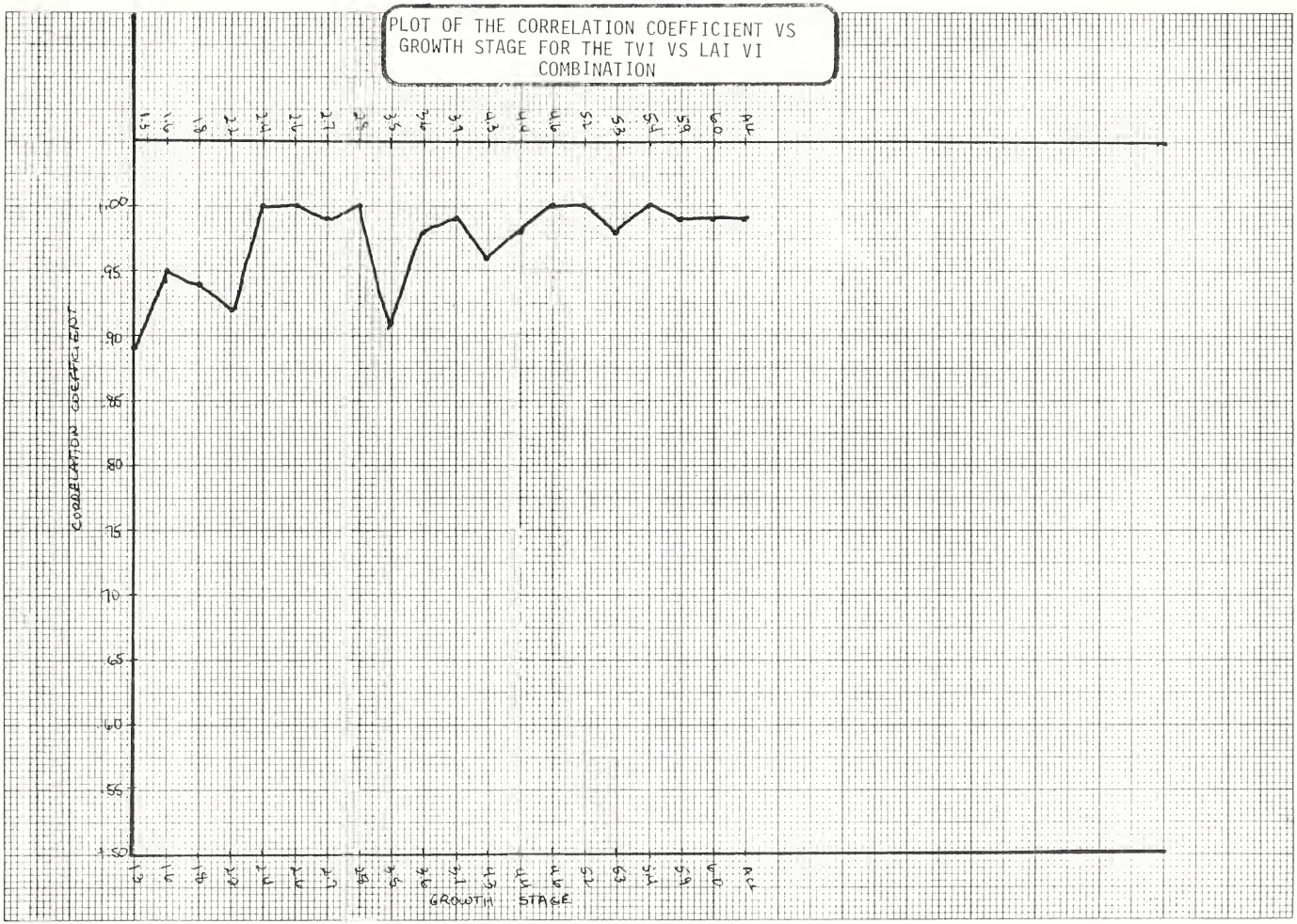
CORRELATION COEFFICIENT
GROWTH STAGE


PLOT OF THE CORRELATION COEFFICIENT VS GROWTH STAGE FOR THE TVI VS LAI VI COMBINATION
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.80
.75
.70
.65
.60
.55
.50
1.5
1.6
1.8
2.2
2.4
2.6
2.7
3.5
3.6
3.7
4.3
4.4
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5.3
5.4
5.9
6.0
ACC
GROWTH STAGE

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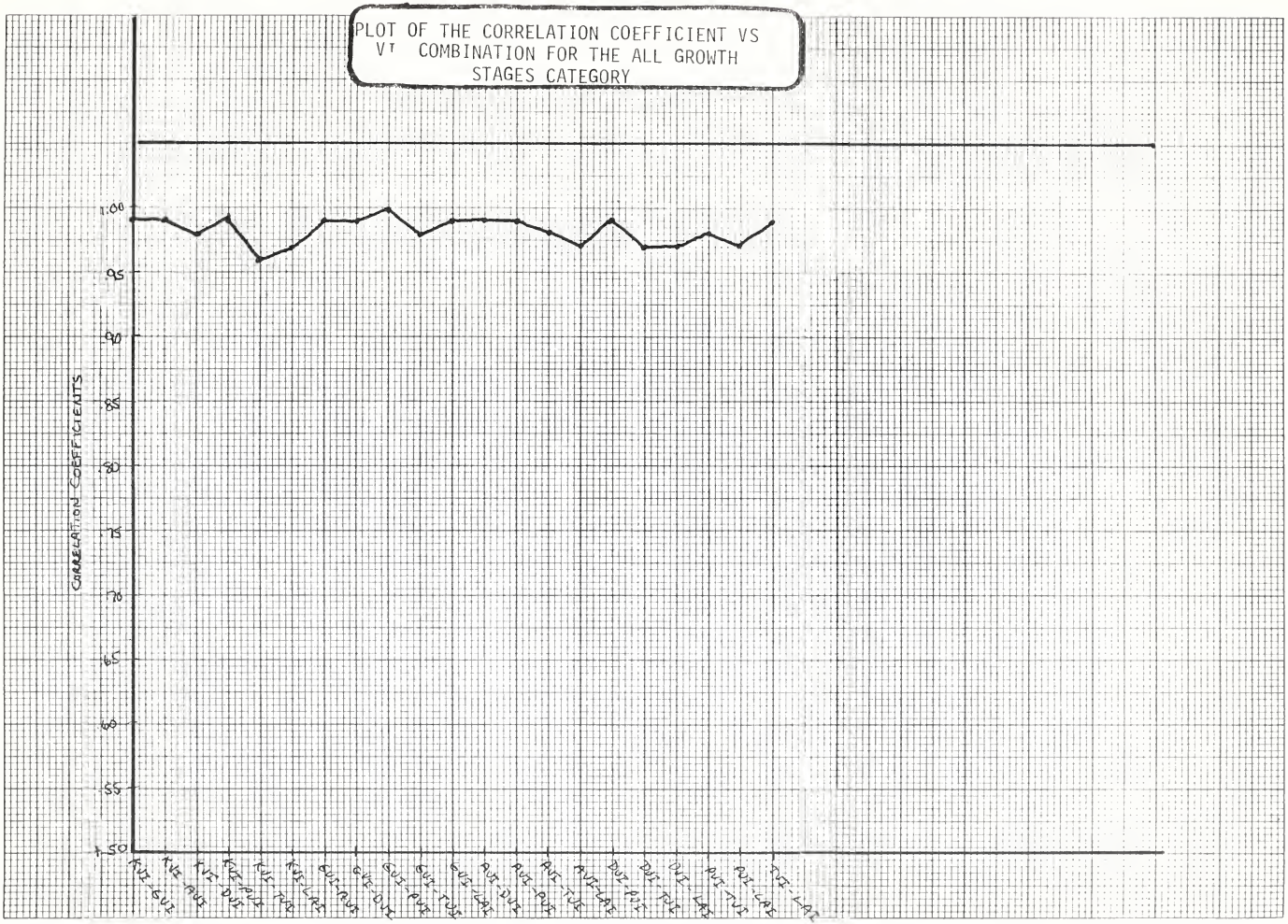
APPENDIX D

LIST OF FIGURES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VT COMBINATION FOR THE ALL GROWTH
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.75
.70
.65
.60
.55
.50
KVZ-EVZ
KVZ-PVZ
KVZ-DVZ
KVZ-PDVZ
KVZ-TVZ
KVZ-LAVZ
EVZ-PVZ
EVZ-DVZ
EVZ-PDVZ
EVZ-TVZ
EVZ-LAVZ
PVZ-DVZ
PVZ-PDVZ
PVZ-TVZ
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PDVZ-LAVZ
TVZ-LAVZ

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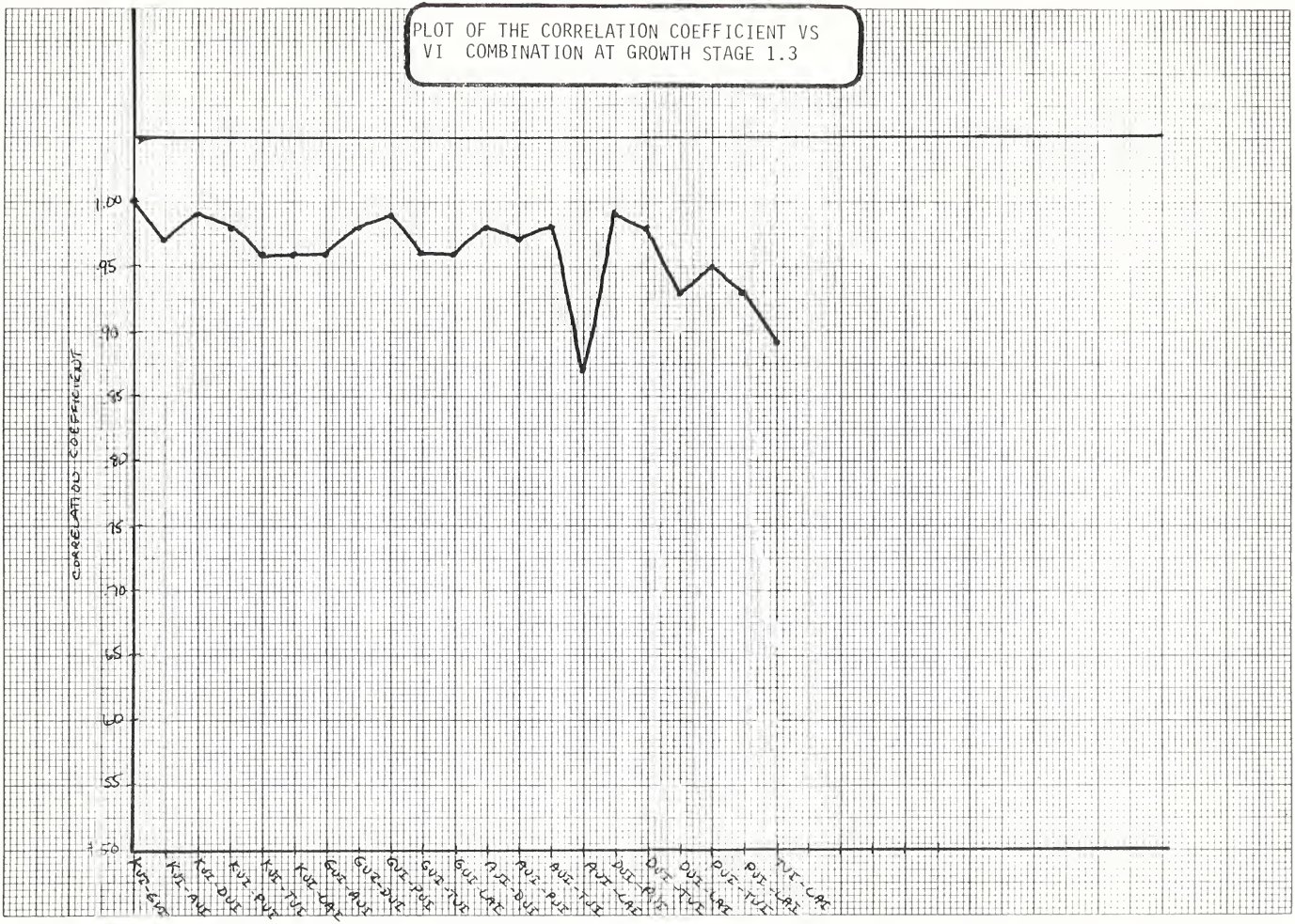
PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 1.3
CORRELATION COEFFICIENT
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.80
.75
.70
.65
.60
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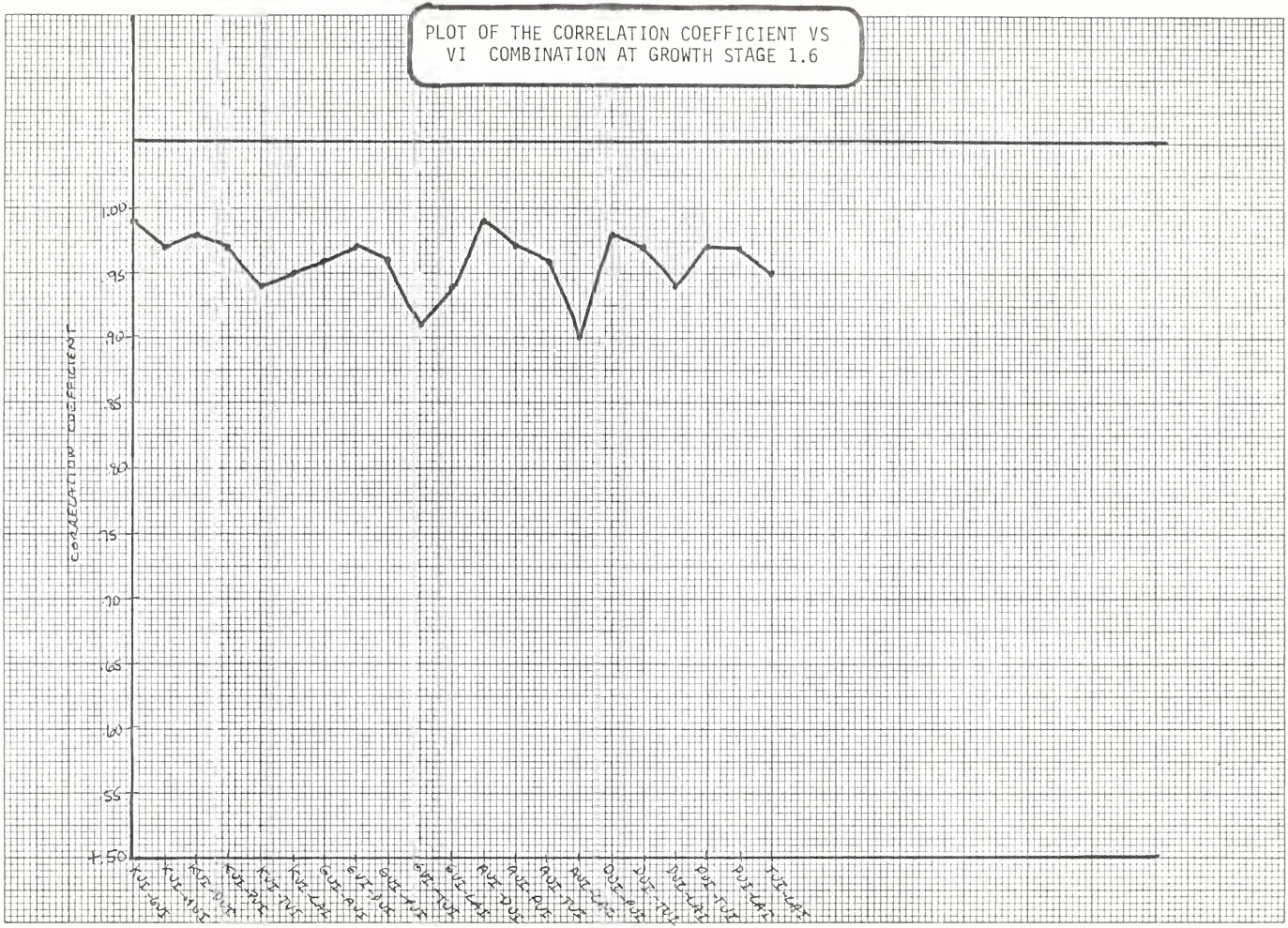
FEB 9 1979


PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 1.6
CORRELATION COEFFICIENT
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50

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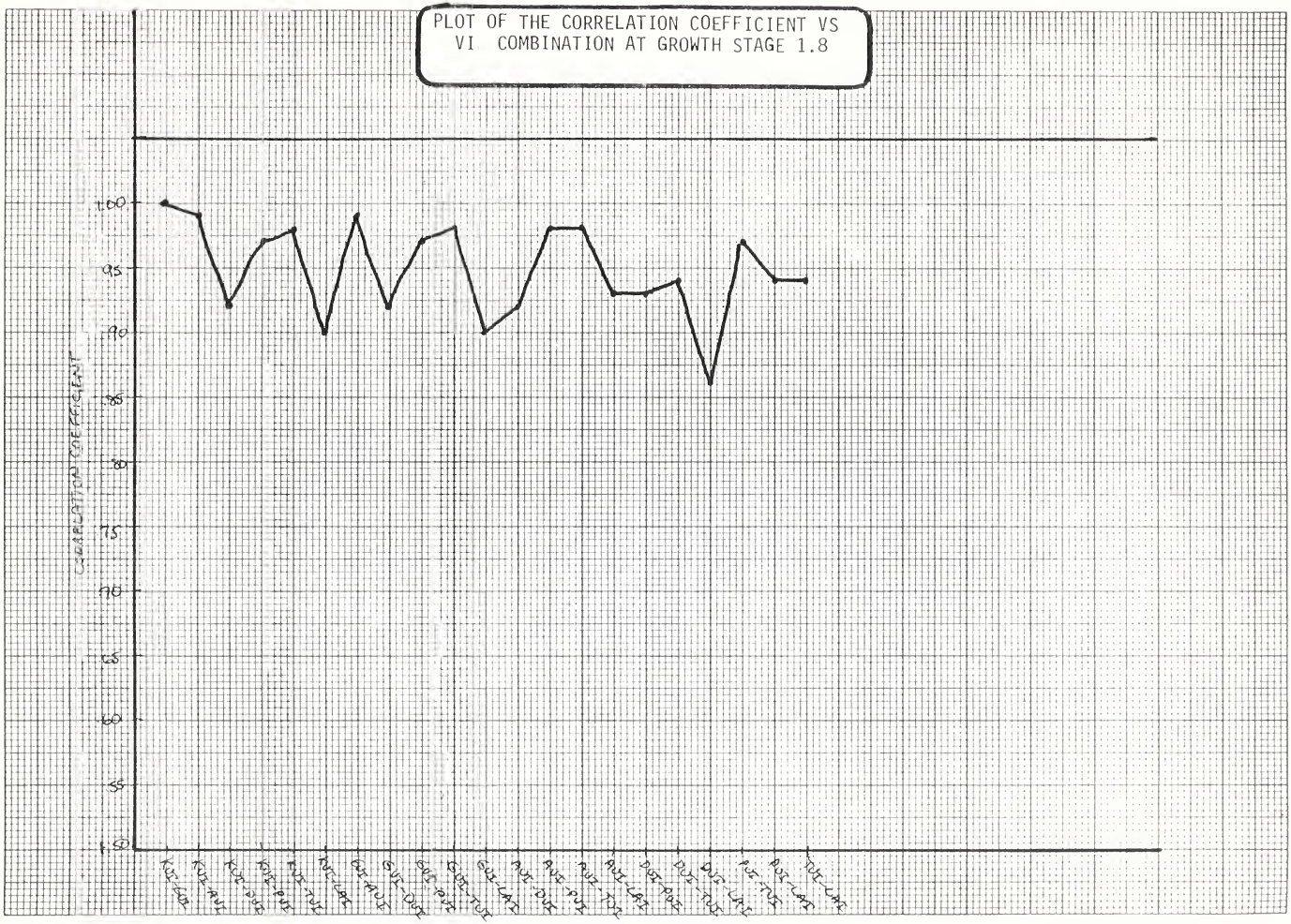
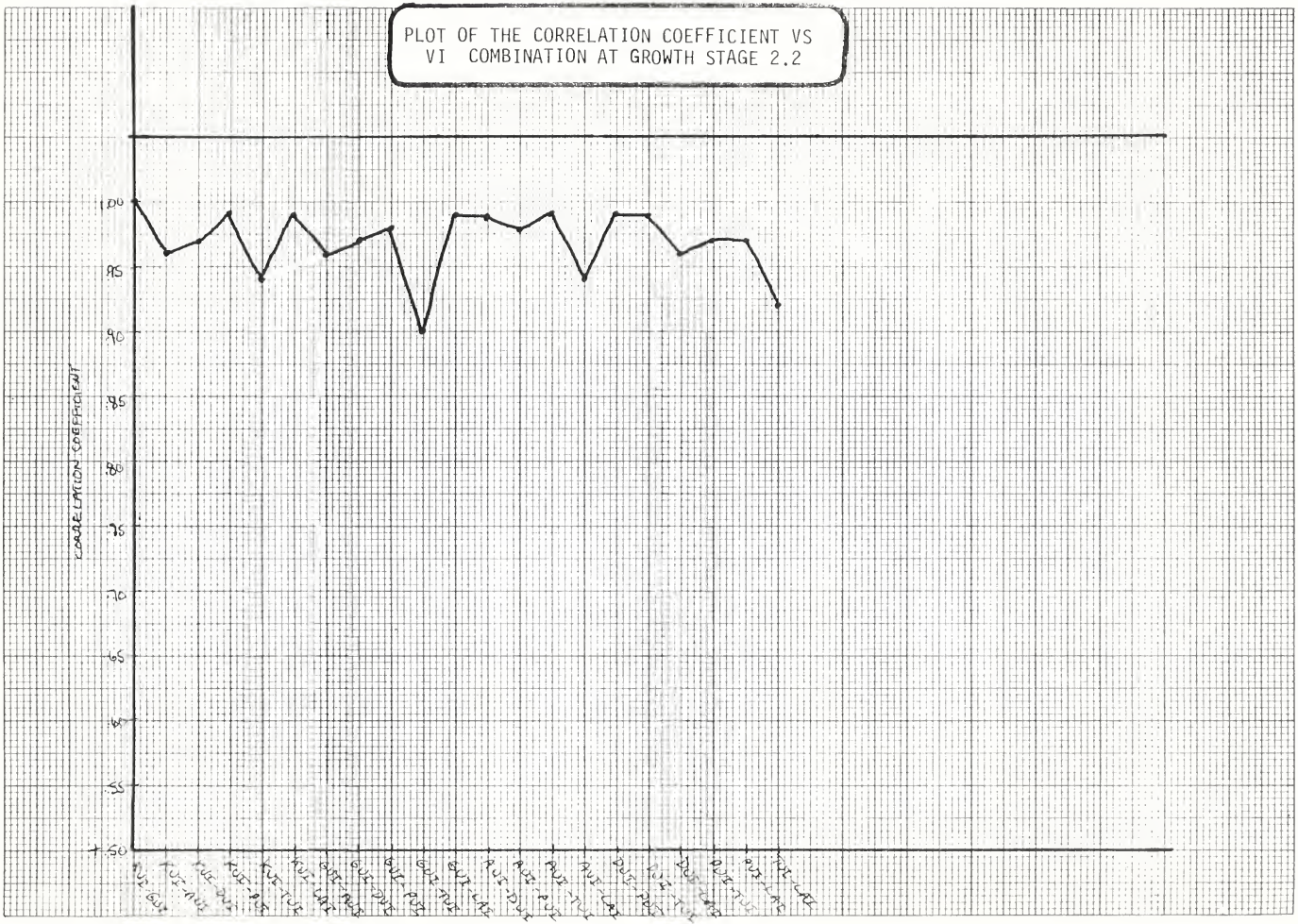
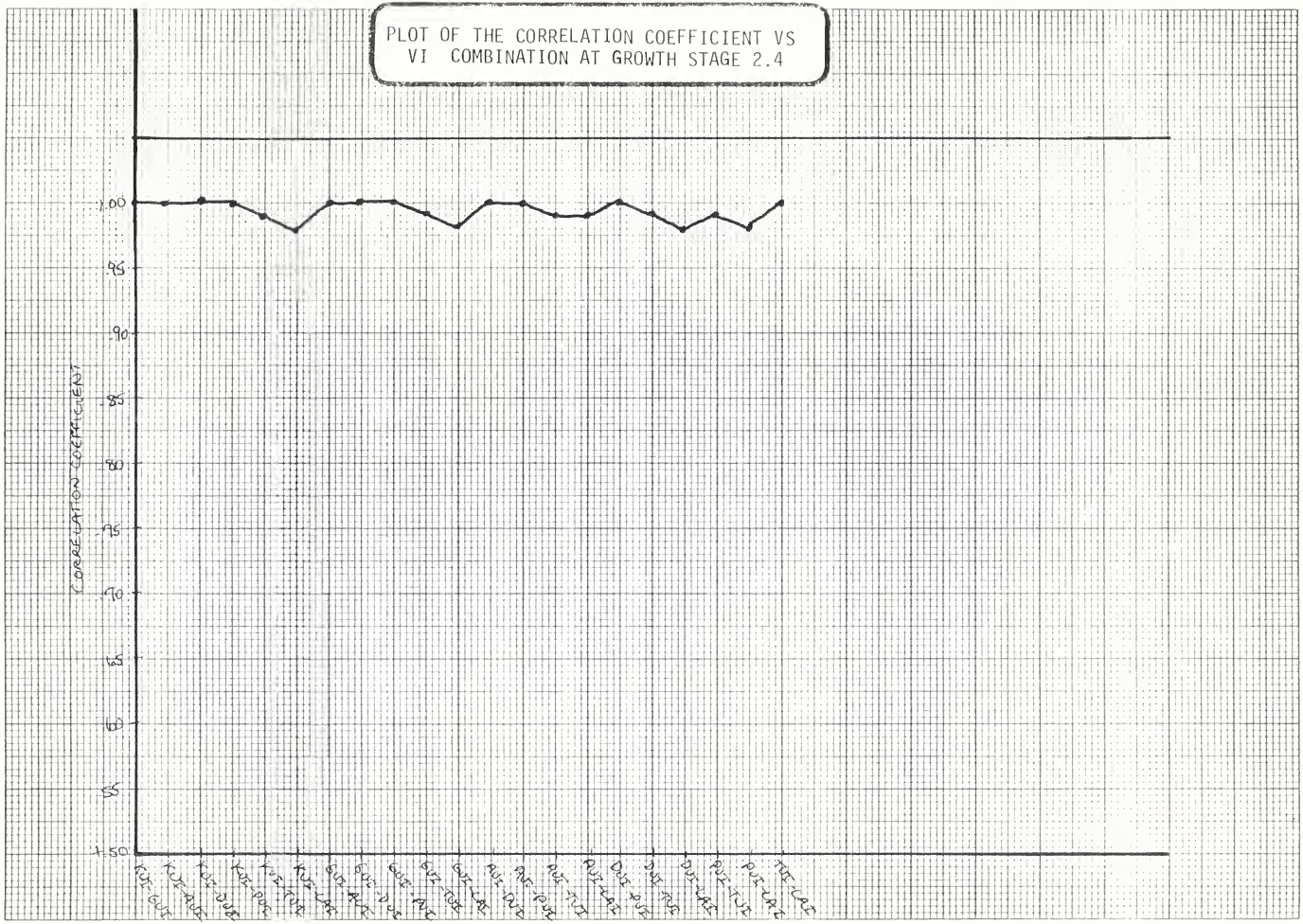
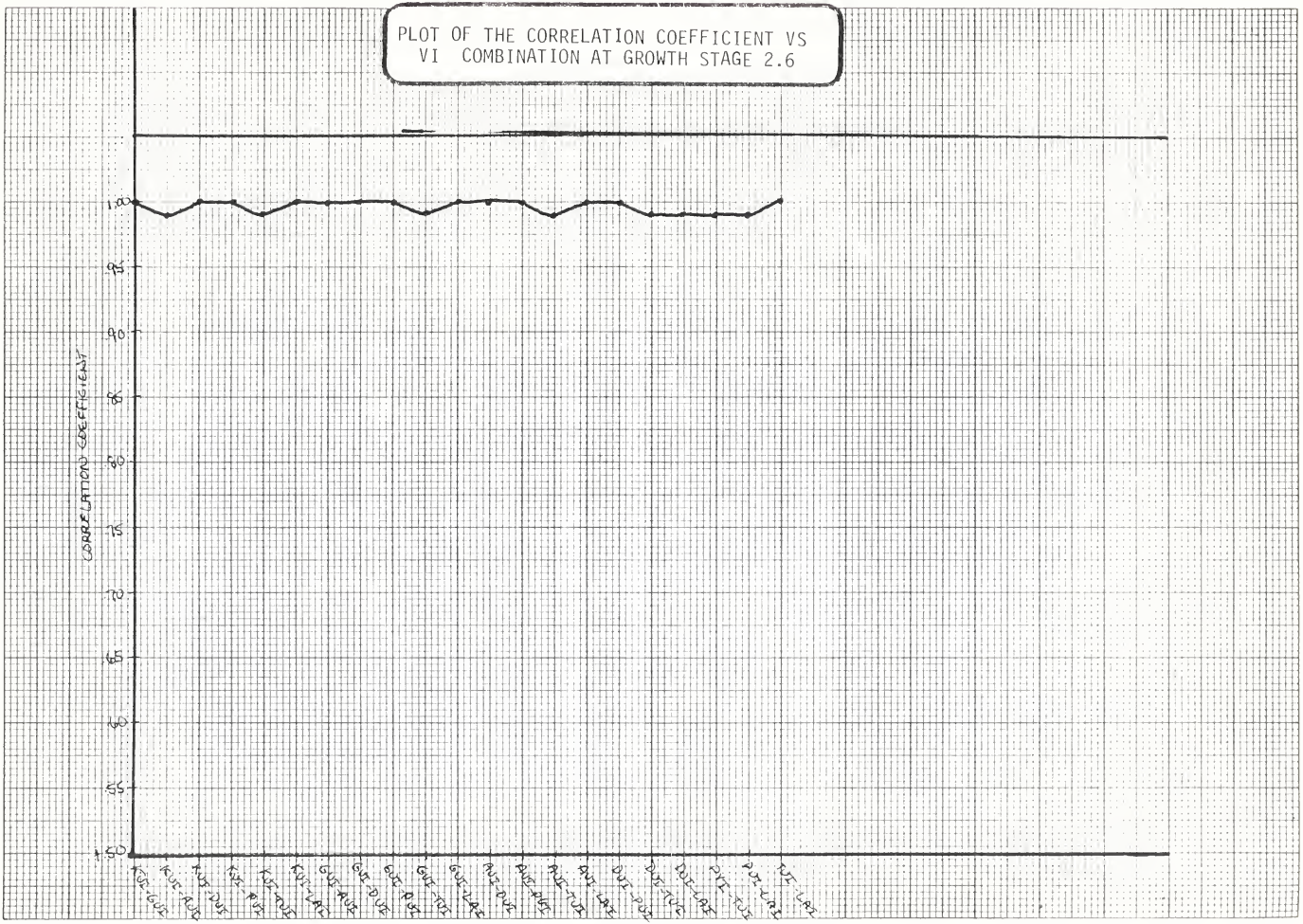

PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 1.8
CORRELATION COEFFICIENT
100
95
90
85
80
75
70
65
60
55
50

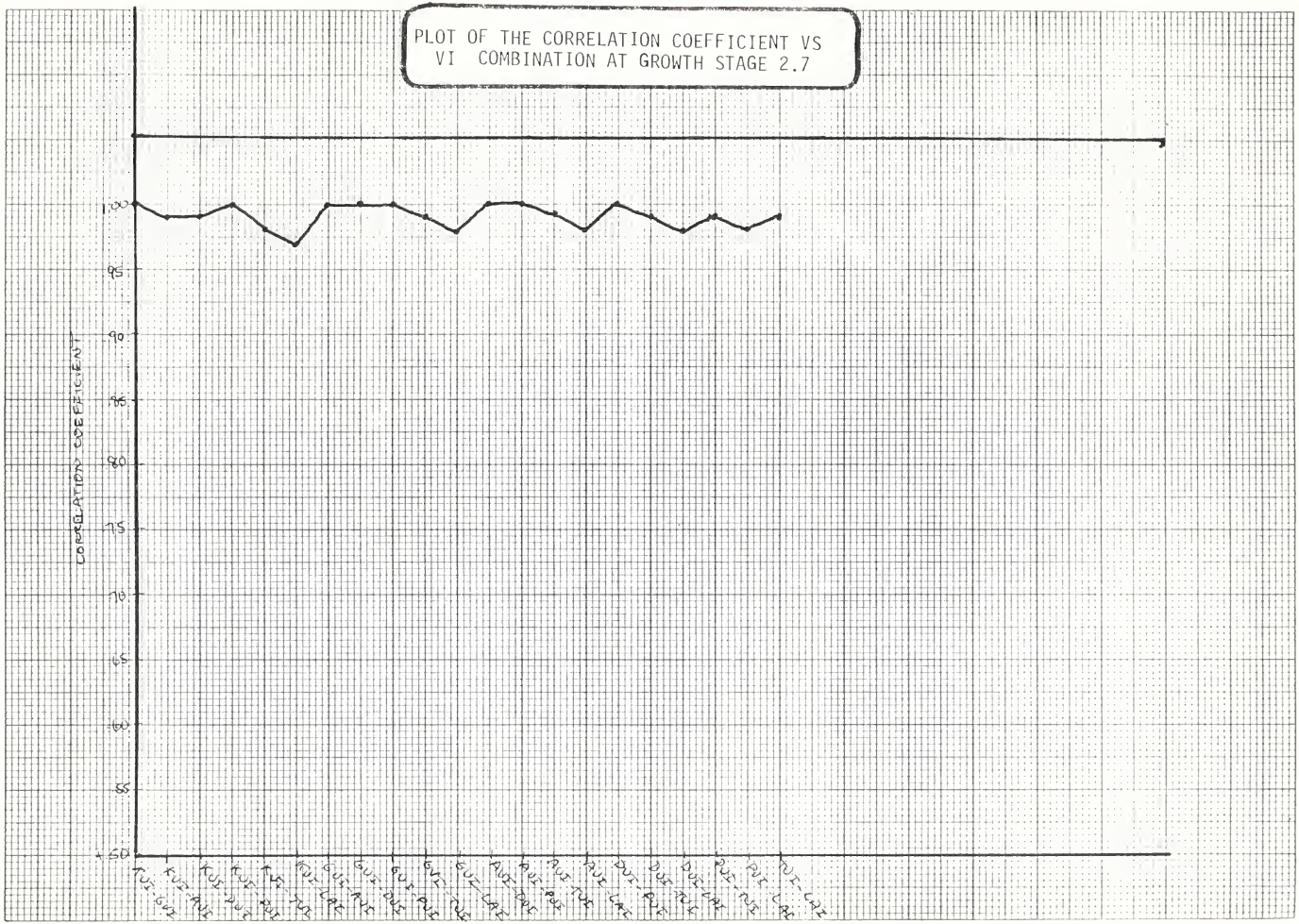

PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 2.2
CORRELATION COEFFICIENT


PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 2.4
CORRELATION COEFFICIENT
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50

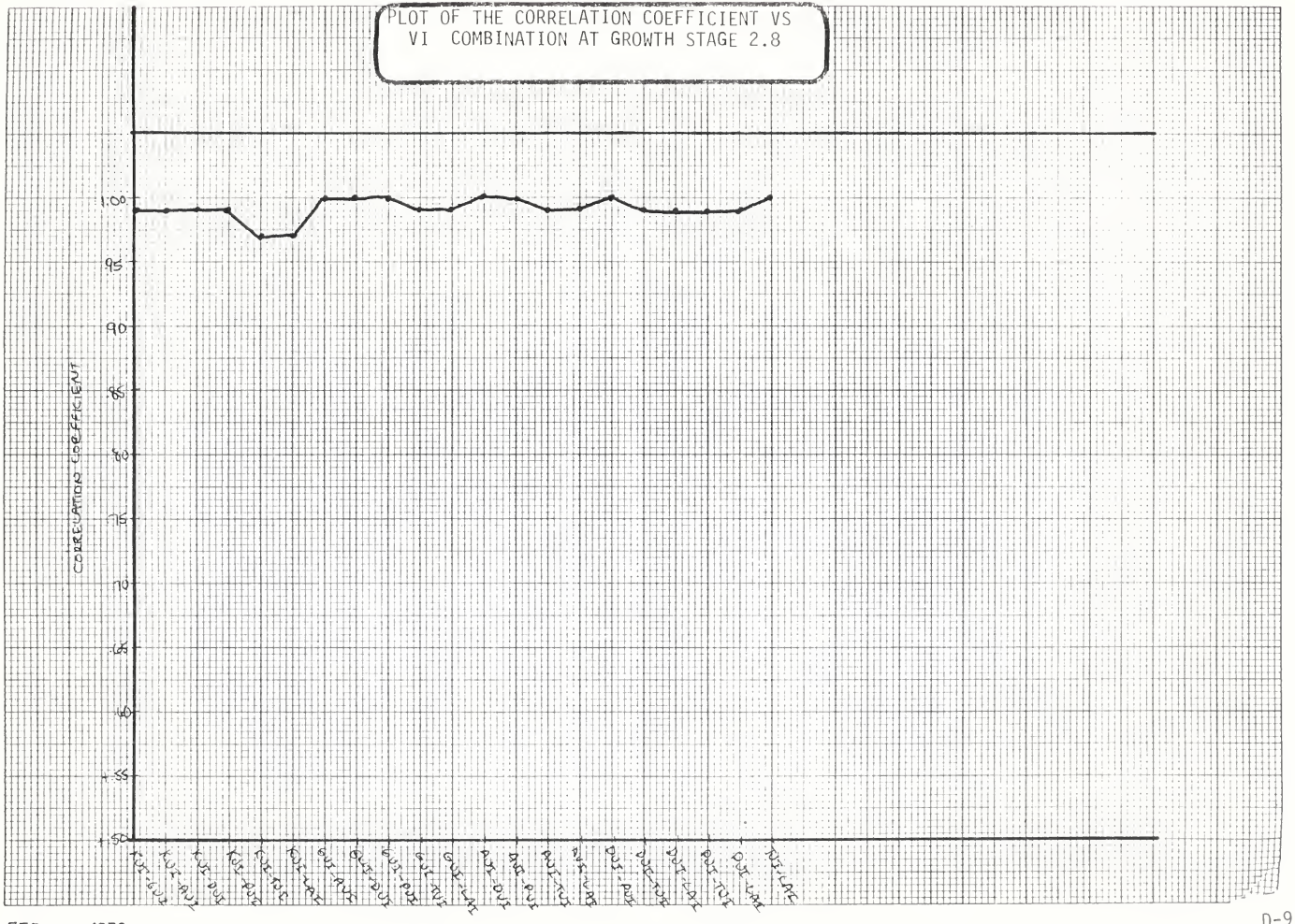
FEB 9 1979


PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 2.6
CORRELATION COEFFICIENT
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50

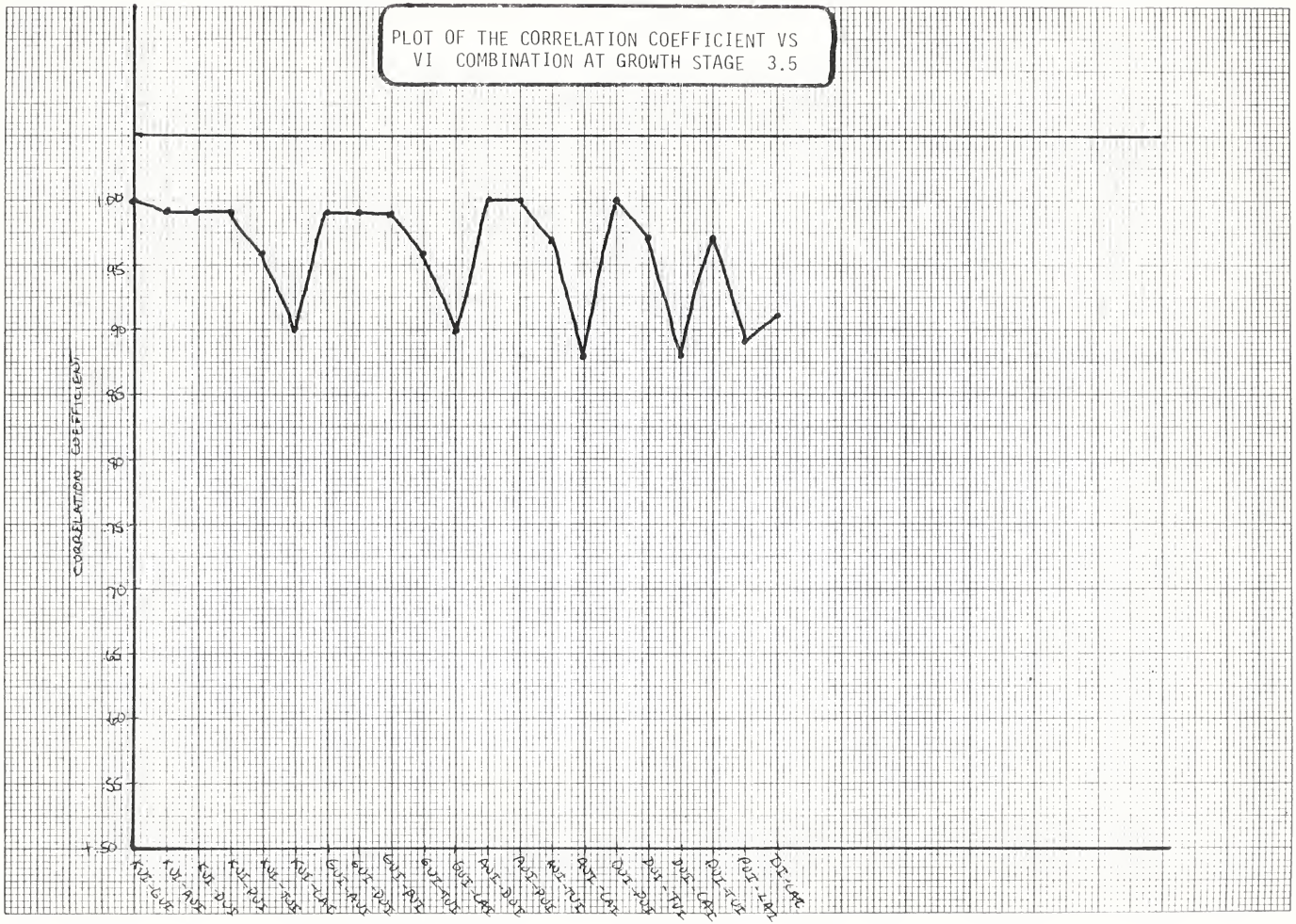
FEB 9 1979

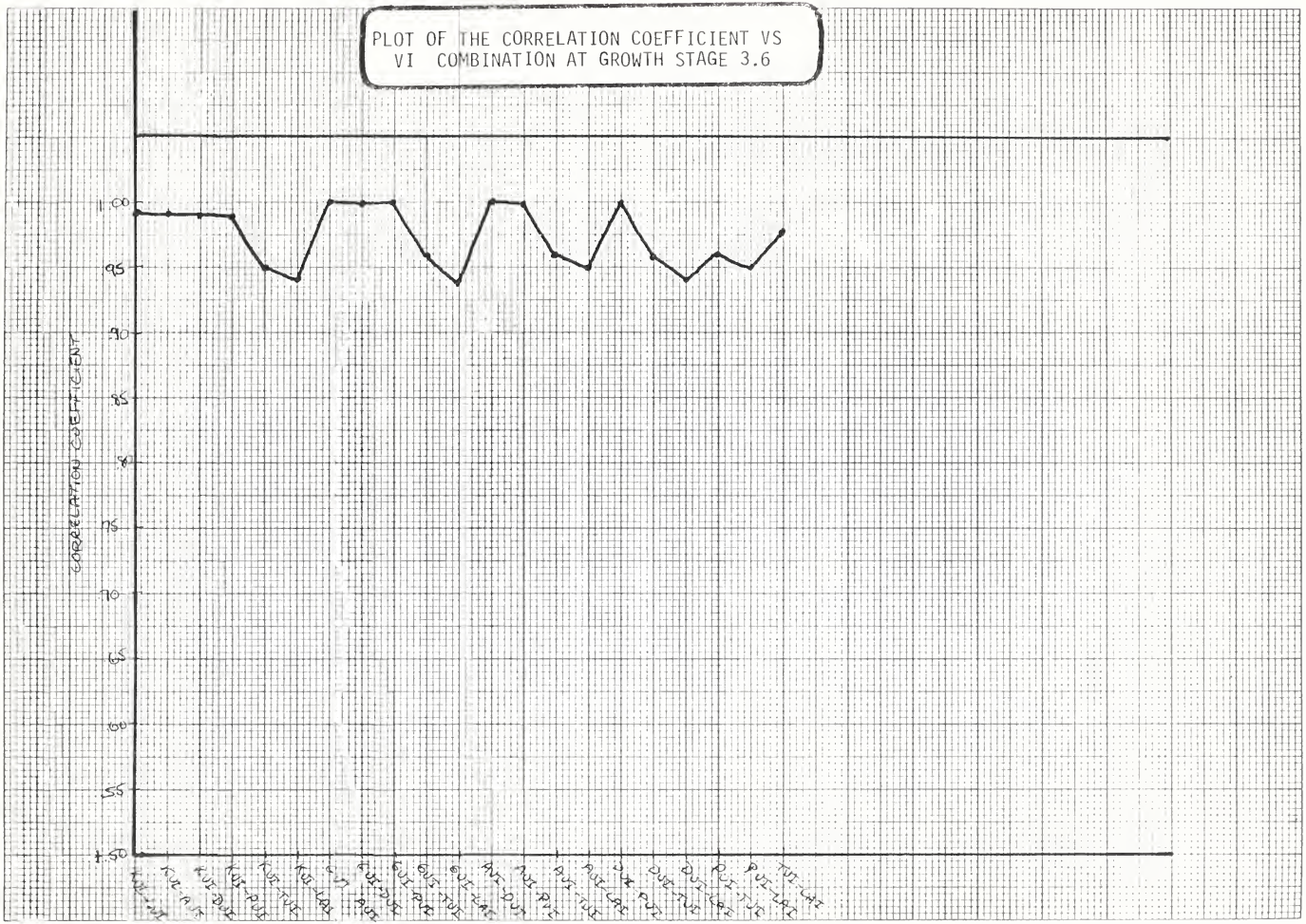

PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 2.7
CORRELATION COEFFICIENT

FEB 9 1979

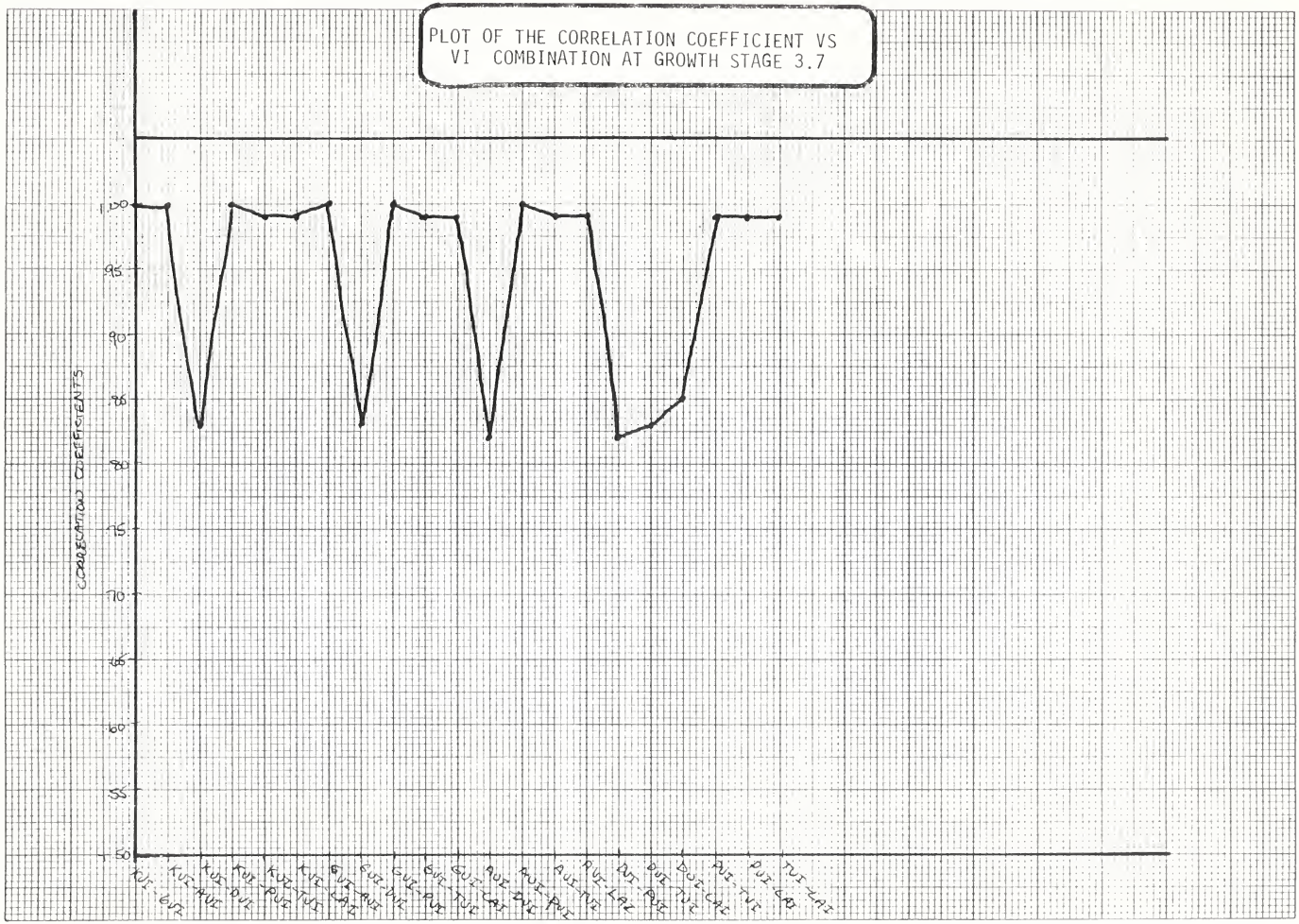

PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 2.8
CORRELATION COEFFICIENT
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50

FEB 9 1979

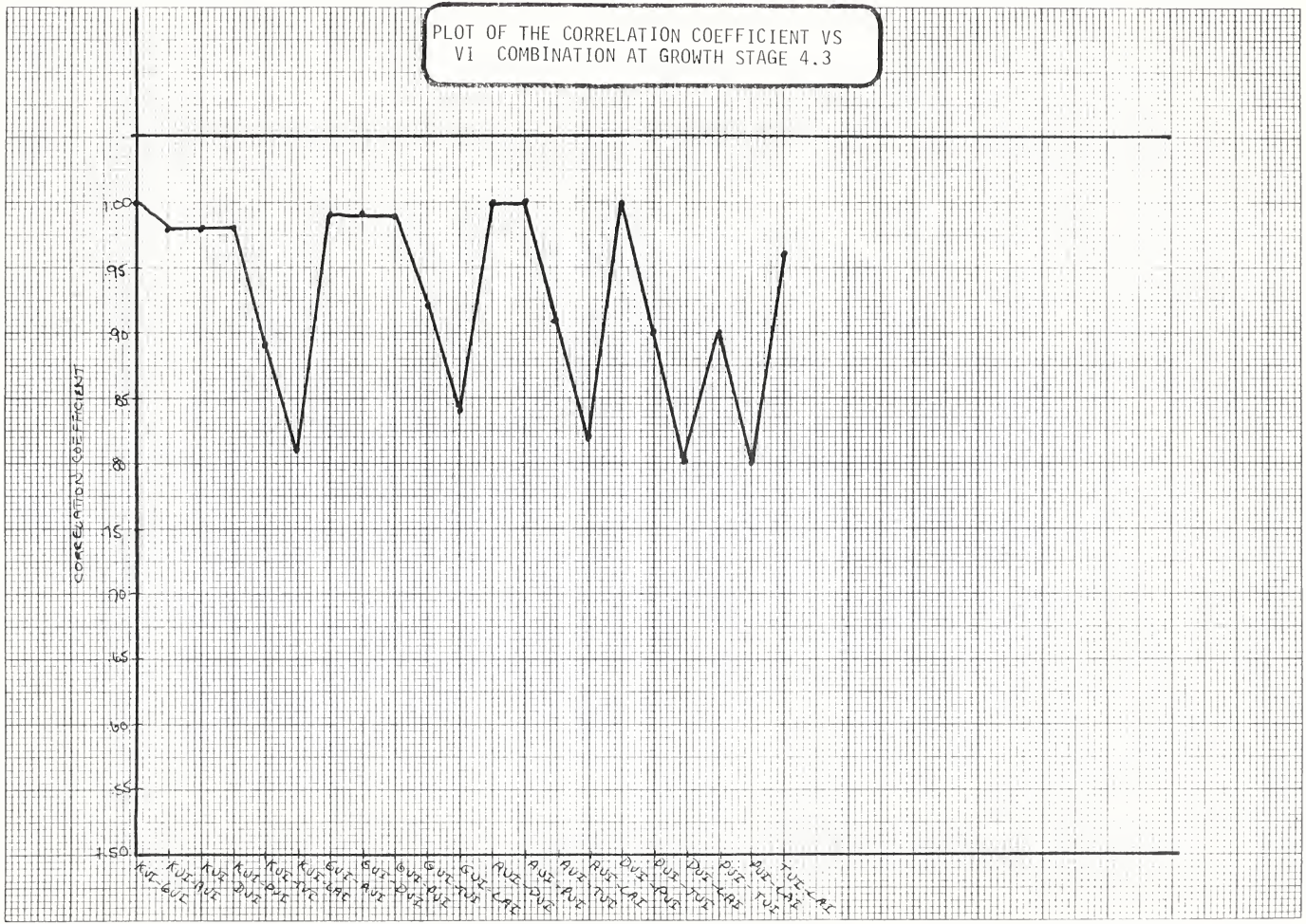

PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 3.5
CORRELATION COEFFICIENT

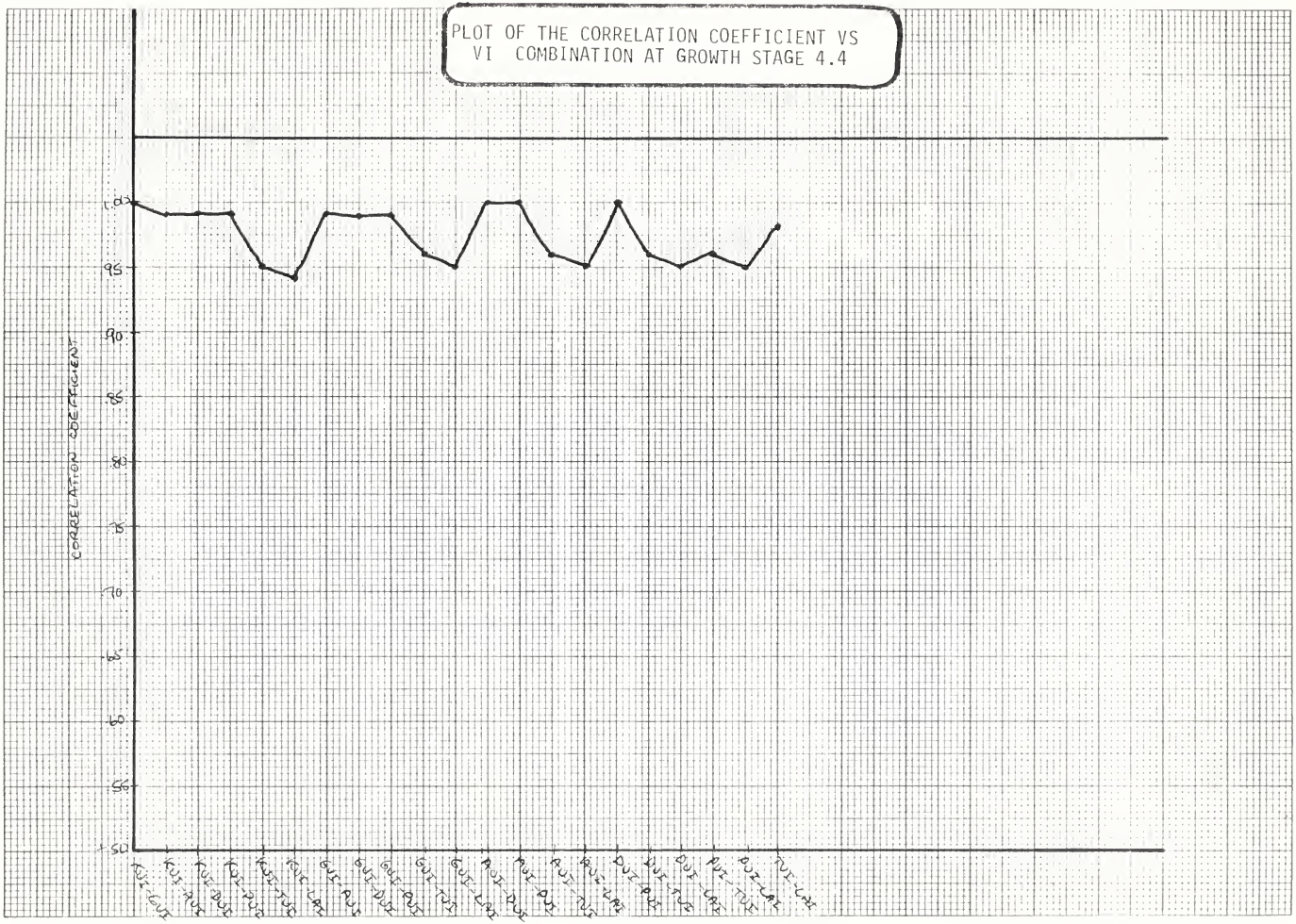

PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 3.6
CORRELATION COEFFICIENT

FEB 9 1979


PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 3.7
CORRELATION COEFFICIENTS
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50

FEB 9 1979


PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 4.3
CORRELATION COEFFICIENT
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
1.50


PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 4.4
CORRELATION COEFFICIENT
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.90
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.80
.75
.70
.65
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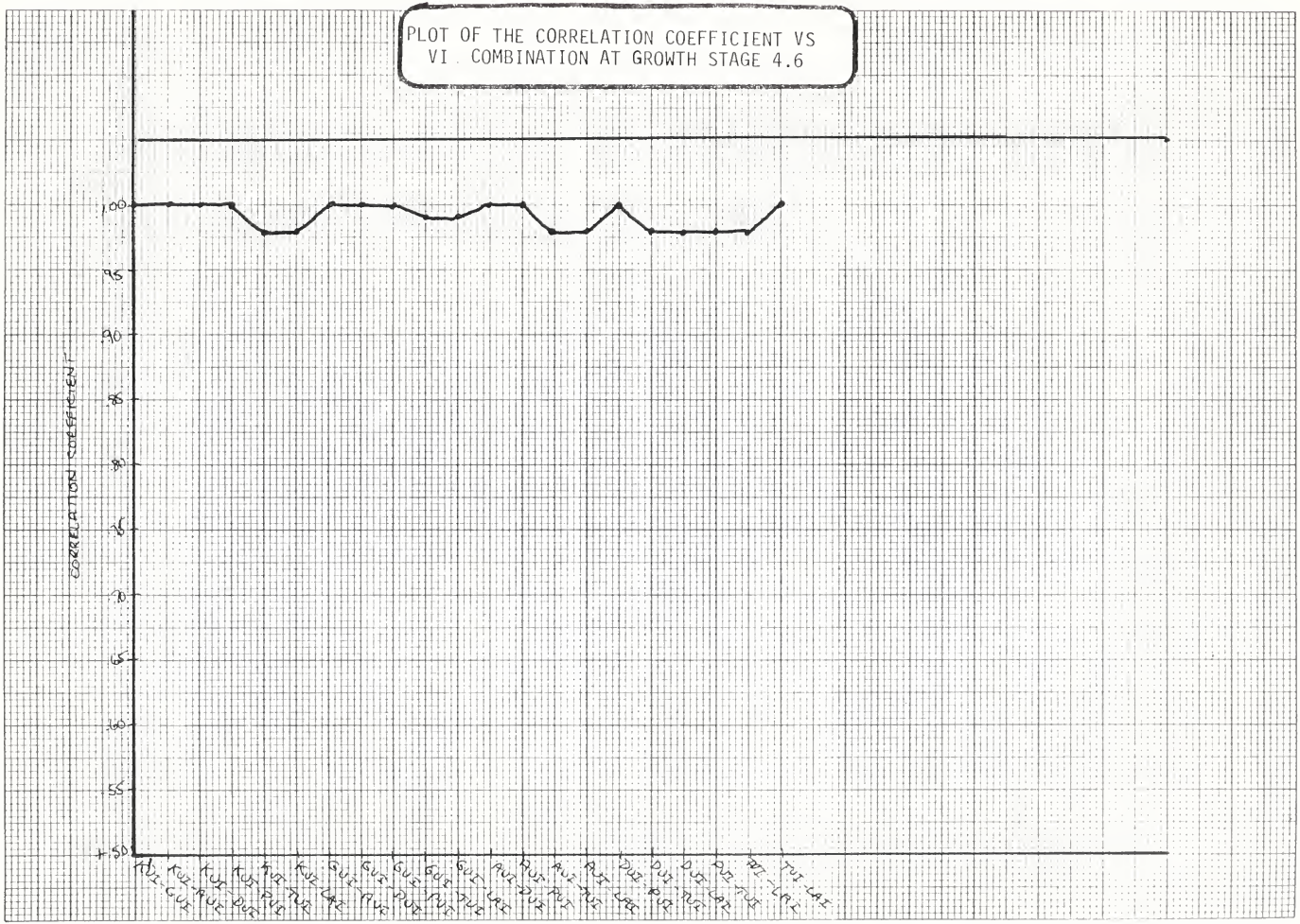
.55
.50

FEB 9 1979


PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 4.6
CORRELATION COEFFICIENT
1.00
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.90
.85
.80
.75
.70
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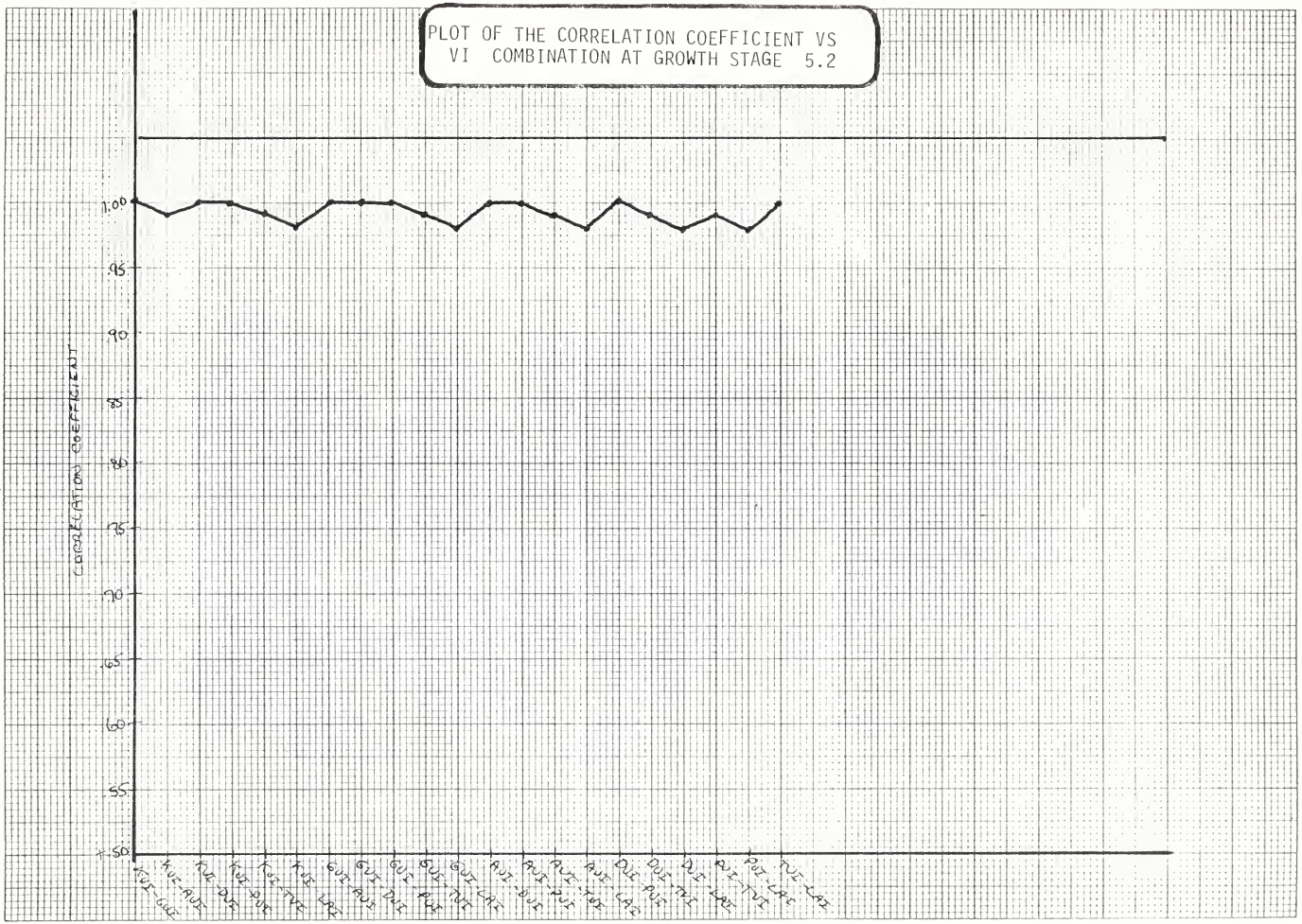
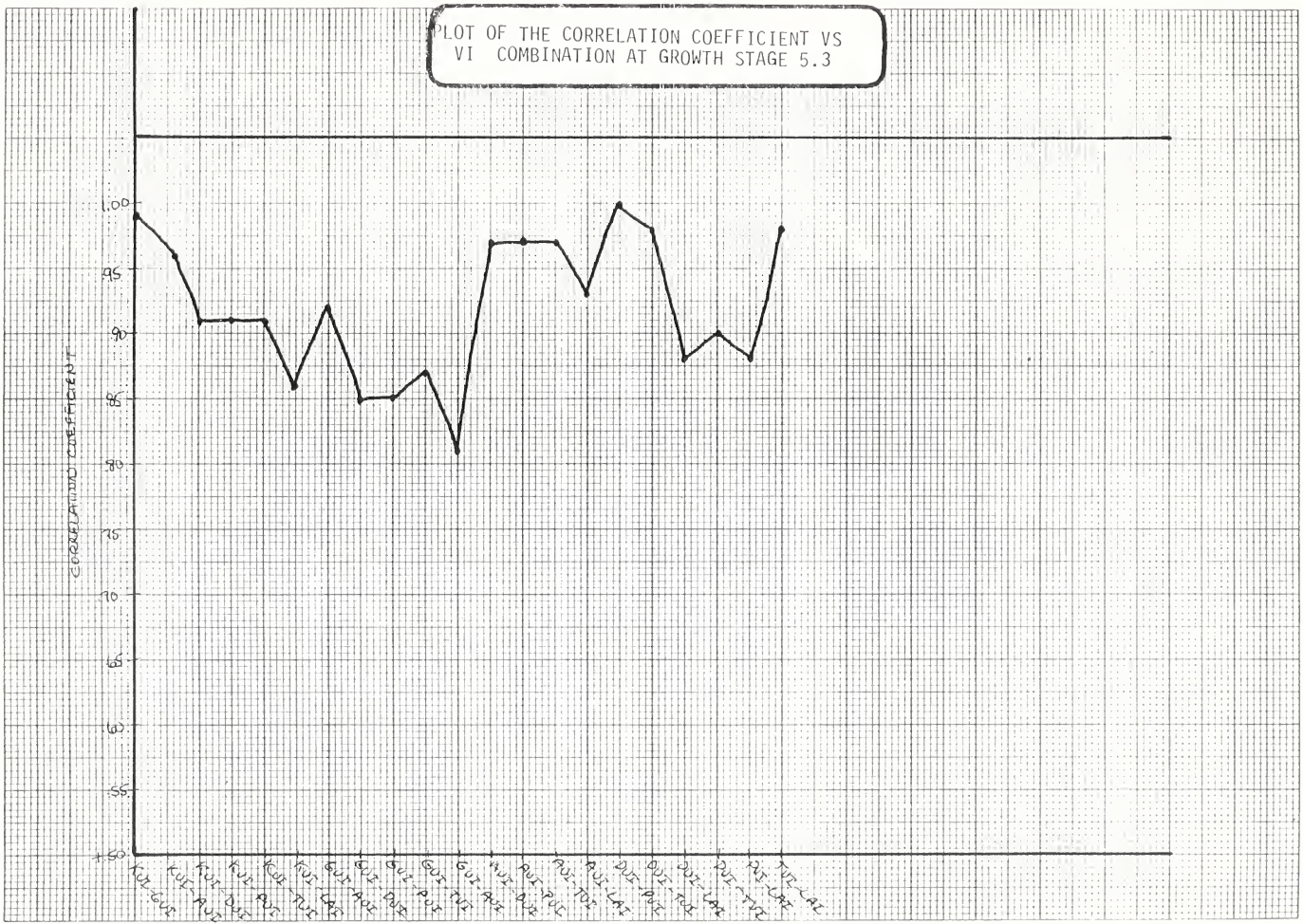
.60
.55
.50


PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 5.2
CORRELATIONS COEFFICIENT
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50


PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 5.3
CORRELATION COEFFICIENT
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50

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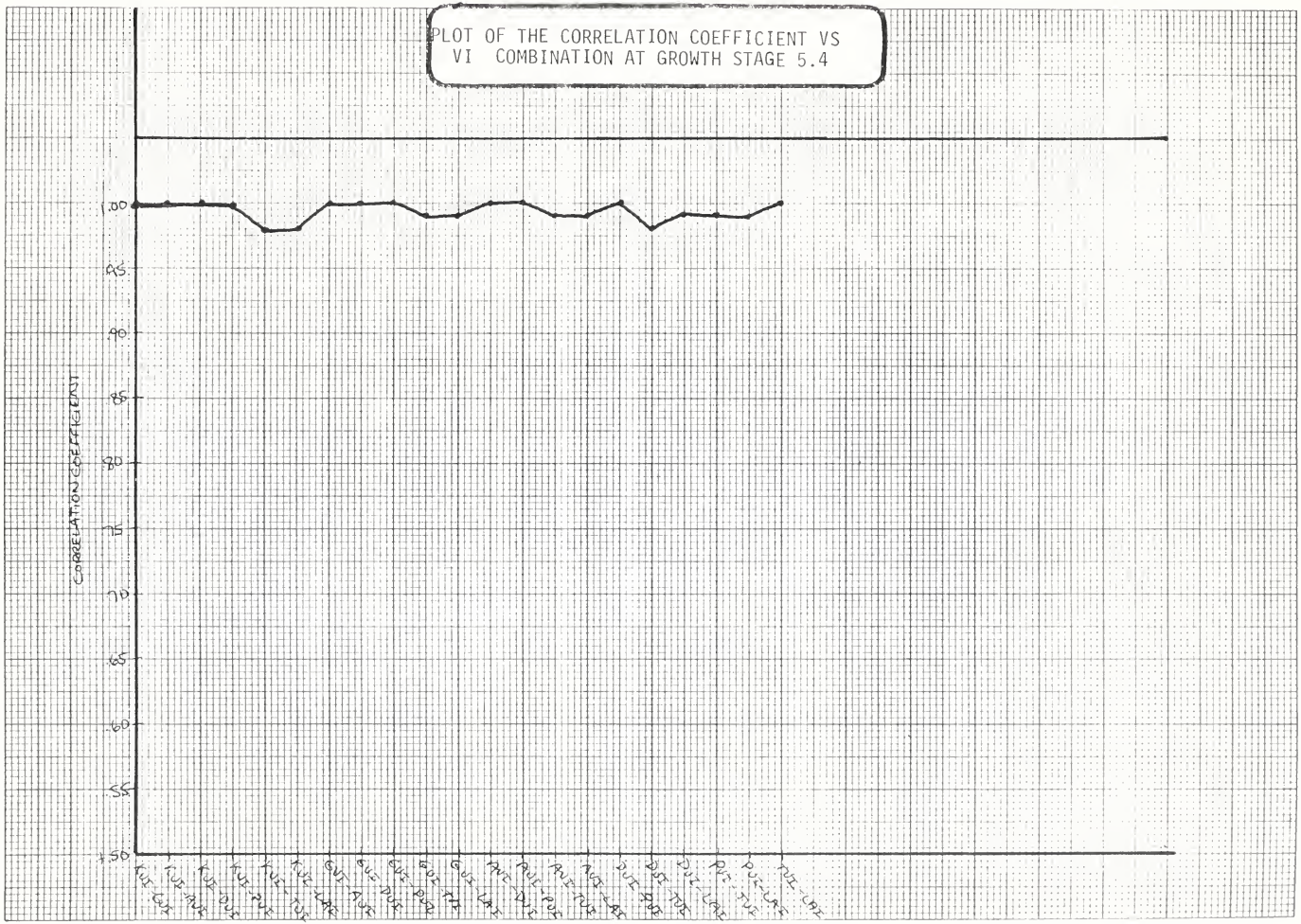
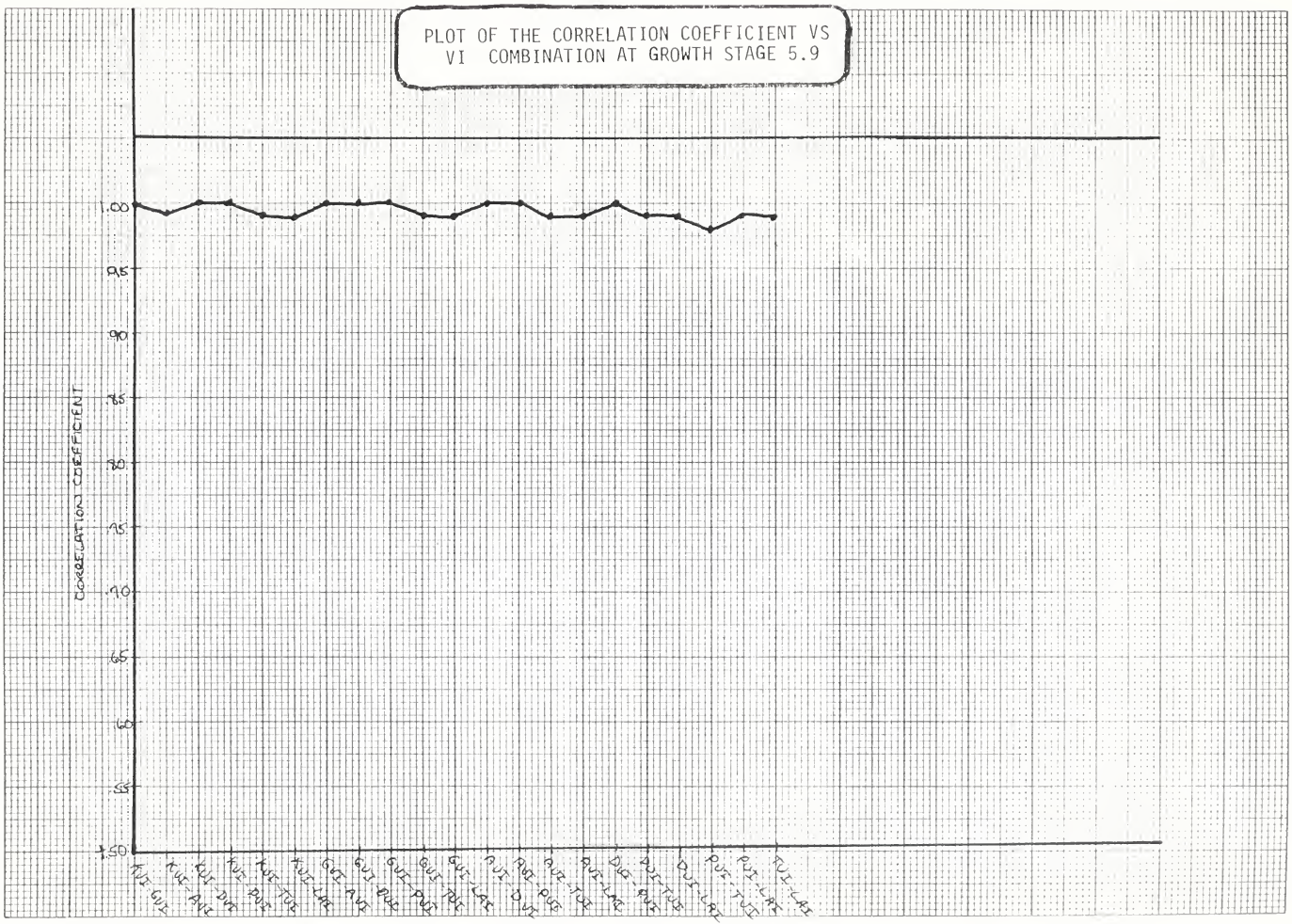

PLOT OF THE CORRELATION COEFFICIENT VS
VI COMBINATION AT GROWTH STAGE 5.4
CORRELATION COEFFICIENT
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50


PLOT OF THE CORRELATION COEFFICIENT VS VI COMBINATION AT GROWTH STAGE 5.9
CORRELATION COEFFICIENT
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50